QA: L

Civilian Radioactive Waste Management System
Management & Operating Contractor

Diffusive Barrier and Getter Under Waste Packages VA Reference Design Feature Evaluations

B00000000-01717-2200-00213 REV 00

May 1999

Prepared for:

U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Prepared by:

TRW Environmental Safety Systems Inc.
1261 Town Center Drive
Las Vegas, Nevada 89134-6352

Under Contract Number
DE-AC08-91RW00134

Civilian Radioactive Waste Management System
Management & Operating Contractor

Diffusive Barrier and Getter Under Waste Packages
LA Reference Design Feature Evaluations

B00000000-01717-2200-00213 REV 00

May 1999

Prepared by:

Robert S. Saunders
for Katherine MacNeil

May 24, 1999
Date

Checked by:

Gerald R. Thiers
Gerald R. Thiers

5/25/99
Date

K. Zarrabi
Kaveh Zarrabi

5/25/99
Date

Approved by:

D. G. McKenzie III
Daniel G. McKenzie III

5/25/99
Date

EXECUTIVE SUMMARY

This technical document evaluates those aspects of the diffusive barrier and getter features which have the potential for enhancing the performance of the Viability Assessment (VA) Reference Design and are also directly related to the key attributes of the repository safety strategy of that design.

The diffusive barrier may be comprised of dry, granular, compacted material, such as layers of gravel-sized crushed tuff and fine-grained sand, placed above the concrete invert (See Figure 1). In this technical document, one placement configuration for the diffusive barrier is evaluated (Figure 1). The thickness of the diffusive barrier layers is bounded by the dimensions of the VA emplacement drift design. The thickness of the diffusive barrier materials is limited to the depth of the concrete invert. Therefore, the diffusive barrier is comprised of a 0.3 m thick layer of fine-grained sand surrounded by two 0.1 m thick layers of gravel-sized crushed tuff (Section 7.1.2). These materials are placed in continuous layers, extending along the length of drift used for emplacement. Therefore, there are no piers used with this design.

The diffusive barrier materials are envisioned to be a media placed below the waste package in which diffusion is the dominant mass transport mechanism. If seepage is at a low flux rate then radionuclide transport through the diffusive barrier is dominated by diffusion rather than advection-dispersion. Due to the low rate of mass transport by diffusion, the barrier may increase the breakthrough time of radionuclides from the Engineered Barrier System (EBS) and therefore the arrival of radionuclides at the accessible environment would be delayed.

The effects of advection, hydrodynamic dispersion, and diffusion on the radionuclide migration rates through the diffusive barrier were determined through the application of the one-dimensional, advection/dispersion/diffusion equation (CRWMS M&O 1999a, Item 3, p.4 of 27). The results showed that because advective flow described by the advection-dispersion equation equation dominates, the diffusive barrier feature alone would not be effective in retarding migration of radionuclides. However, if the diffusive barrier were combined with one or more features that reduced the potential for advection, then transport of radionuclides would be dominated by diffusion and their migration from the EBS would be impeded.

The getter barrier may be comprised of a fine-grain sized material that has an affinity for radionuclides. A silt-sized getter material is proposed, because the finer-sized materials will tend to wick or draw water resulting in more effective sorption. It also provides more surface area for chemical sorption. For the purpose of this technical document, apatite is chosen as the getter material for a number of reasons. Firstly, apatite is stable both thermally and chemically; secondly, it has a strong sorptive capacity for neptunium (Np-237), which is one of the major radionuclides that will be released to the accessible environment upon waste package breach; and thirdly, experimental sorption data for both Np-237 and technetium (Tc-95m) is available for apatite. The study only examined apatite as a getter and due to limited time was not able to examine other materials. Apatite is effective at adsorbing Np but is not effective at adsorbing Tc which is the radionuclide that is the largest contributor to the annual radiological dose rate in the first 10,000 years. Some limited information does exist on a few other potential getters (e.g. iron oxides). However, further work would be needed to evaluate the efficacy of these other getters.

In this technical document, two getter configurations (Case 1 and Case 2) are developed (See Section 7.2.7.2). Both getter configurations consist of layers of gravel-sized crushed tuff and silt-sized apatite of varied thickness. The Case 1 getter configuration requires a 6.5 m diameter drift with a 200 mm concrete liner. The case 1 getter configuration consists of a 1.2 m thick layer of apatite, surrounded by two 0.5 m thick layers of crushed tuff. The apatite and crushed tuff layers are placed (See Figure 5) in continuous layers above the concrete invert, extending along the length of emplacement drift. The Case 2 getter configuration conforms to the VA design for emplacement drift diameter. A layer of apatite, 0.3 m thick, is surrounded by two layers of gravel-sized crushed tuff, 0.1 m thick. As with Case 1 the layers of apatite and crushed tuff are placed on the concrete invert (See Figure 6). . There are no piers used with this design. In the Case 1 getter configuration, the top layer of crushed tuff is above the top of the concrete invert, therefore the track ties and rail will have to be placed upon this top layer.

As in the evaluation of the diffusive barrier, the effects of advection, hydrodynamic dispersion, and diffusion on the rates of migration of radionuclides through the getter are evaluated. However, in addition to these mechanisms, the one-dimensional advection/dispersion/diffusion model is modified to include the effect of sorption on radionuclide migration rates through the sorptive medium (getter) (CRWMS M&O 1999a, Item 3, p. 6 of 27). As a result of sorption, the longitudinal dispersion coefficient, and the average linear velocity are effectively reduced by the retardation factor. The retardation factor is a function of the getter material's dry bulk density, sorption coefficient and moisture content.

The results of the evaluation showed that a significant delay in breakthrough through the getter can be achieved if the thickness of the getter barrier is increased. These results concur with the performance assessment analysis which showed a dose rate of 25 mrem/year reaching the accessible environment at 150,000 years after repository closure for the VA base case compared with 225,000 years after repository closure for the Case 1 getter configuration (See Section 7.2.8, Figure 12). In addition, the Case 1 getter configuration dose rate is substantially reduced between 50,000 and 300,000 years after repository closure compared with the VA base case dose rate. For example, at 200,000 years after repository closure, the dose rate at the accessible environment for Case 1 is lower than the VA base case by almost a factor of five with estimated doses at 15 mrem/year and 70 mrem/year, respectively (Section 7.2.8, Figure 12).

The aspects of the two design features, which have the potential to enhance design performance in accordance with the License Application Design Selection (LADS) evaluation criteria, are identified and evaluated relative to the VA design (Appendices A and B). The evaluation criteria describe the features in terms of their post-closure performance, pre-closure performance, assurance of safety, engineering acceptance, construction, operations, and maintenance, schedule, cost, and environmental considerations. A rating of 1 to 5 is applied to each evaluation criterion question with the exception of post closure performance, cost, schedule and environmental considerations. In comparison to the VA reference design, a rating of one and two indicates significant to moderate disadvantages, respectively, associated with these design features, a three would indicate equivalence to the VA design, a 4 and 5 indicates moderate to significantly higher advantages, respectively, associated with these design features. The paragraphs below provide a summary of the evaluation criteria questions.

Post-closure Performance

A post-closure performance assessment was not conducted for the diffusive barrier because the diffusive barrier alone does not enhance the post-closure performance of the repository. It would have to be combined with one or more features in order to reduce the advection-dispersion flow (Section A.1).

The peak dose rate to an average individual of a critical group at a distance of 20 km from the repository site is used as a measure of post-closure performance. The peak dose rate is considered for two time frames, less than 10,000 years and between 10,000 and 1,000,000 years after repository closure. In this analysis, juvenile failure of a single waste package results in releases to the accessible environment occurring at 4,000 years and 3,600 years after emplacement for Case 1 and Case 2, respectively (Section 7.2.8, Figures 11 and 13). The LADS criterion evaluation show that only the getter Case 1 configuration provides a moderate benefit in post-closure performance compared to the VA reference design (Sections 7.2.8, 7.6.1 and Attachment I). The Case 1 getter configuration achieves a significant delay of radionuclide breakthrough from the EBS as well as a reduction in dose rate at the accessible environment, between 50,000 and 300,000 years after repository closure.

The peak dose rates for the VA base case, Case 1 and Case 2 in the first time frame occur at 10,000 years; the values are basically the same and are estimated at 4.22×10^{-2}, 3.96×10^{-2}, and 4.15×10^{-2} mrem/year, respectively. The peak dose rates for the VA base case, Case 1 and Case 2 in the second time frame occur at 317,000 years and are estimated at 300.88, 213.65, and 423.72 mrem/year, respectively (Sections 7.2.8 and A.1). The Figure of Merit (FOM) values of the integrated dose over the two time frames, for the base case, Case 1 and Case 2 getter configurations are 25.02, 16.4, and 23.76 mrem/year, respectively (Section A.1).

Pre-Closure Performance

The pre-closure performance assessments for the diffusive barrier and getter features were comparable to the VA reference design. A rating of 3 is assigned (Sections 7.2.8 and Section A.2).

Assurance of Safety

The diffusive barrier provides an assurance of safety that is comparable to the VA design. The two getter cases provide an assurance of safety in post-closure that is approximately the same as the VA. Therefore, a rating of 3 is assigned (Section A.3).

Engineering Acceptance

The diffusive barrier without other barriers that would reduce advection has a moderately low potential for engineering acceptance and is assigned a rating of 2. The two getter configurations are comparable to the VA design. Therefore a rating of 3 is assigned (Section A.4).

Construction, Operations, and Maintenance

The designs of the diffusive barrier and getter features have moderate disadvantages in construction, operations, and maintenance and are therefore assigned a rating of 2 (Section A.5).

Schedule

The schedules for the construction of the two getter configurations are comparable to the VA design (Section A.6). A construction schedule for the diffusive barrier was not prepared because it is unlikely that the diffusive barrier would be included in the LA design given its poor performance.

Cost

The total costs associated with the two getter configurations are estimated at approximately $1.4 and $1.2 billion, respectively (Table A-1).

CONTENTS

Page

EXECUTIVE SUMMARY iv

1. PURPOSE 1
   1.1 OBJECTIVE 1
   1.2 SCOPE 1
   1.3 BACKGROUND 2

2. QUALITY ASSURANCE 2

3. METHOD 2

4. DESIGN INPUTS 3
   4.1 DESIGN PARAMETERS 3
      4.1.1 Emplacement Drift Details for Case 2 Getter Configurations 3
      4.1.2 Distribution Coefficients (K_d) for Neptunium (Np-237) and Technetium (Tc-95m) on Apatite 3
      4.1.3 Breakthrough Curves Pertaining to the Diffusive Barrier and Getter Evaluation 4
      4.1.4 Total System Performance Assessment results of Two Getter Configurations 4
      4.1.5 Thermal Evaluation of the Getter Configuration 5
      4.1.6 Required Apatite Thickness to Sorb the Np-237 and Tc-99 From a 21 PWR Waste Package 5
      4.1.7 Cost Estimate for the Two Getter Configuration 5
   4.2 DESIGN CRITERIA 6
      4.2.1 Use of Materials That Do Not Degrade Performance of the Waste Packages 6
      4.2.2 The Ex-Container System Limiting Microbial Activity 6
   4.3 ASSUMPTIONS 6
      4.3.1 Getter Barrier System 6
      4.3.2 Thickness of Getter System Materials Unconstrained By VA Emplacement Drift Diameter (Case 1) 6
      4.3.3 Thickness of Getter System Materials for Case 2 6
      4.3.4 Emplacement Drift Diameter of Case 1 Getter Configuration 7
      4.3.5 Rail and Ties for Case 1 Getter Design 7
      4.3.6 Nominal Allowable Bearing Pressure for Medium to Stiff Compacted Silt 7
      4.3.7 Mass and Dimensions of Heaviest Waste Package 7
      4.3.8 Kd values for Tc-95m used as proxy for Kd values for Tc-99 7
      4.3.9 Interim Post-closure Performance Measure 7
      4.3.10 Concrete Liner Used in the Case 1 Emplacement Drift 8
      4.3.11 Top of Concrete Measurement for Case1 Getter Configuration 8
      4.3.12 Contribution of Concrete to the Post-Closure Performance of the Diffuse Barrier or Getter Features 8
      4.3.13 No Adsorption of Colloids onto the Apatite 8

CONTENTS (Continued)

4.4 CODES AND STANDARDS 8

5. REFERENCES 8

6. USE OF COMPUTER SOFTWARE 11

7. DIFFUSIVE BARRIER AND GETTER EVALUATION 12
7.1 EFFECTS OF PERCOLATION ON THE DIFFUSIVE BARRIER DURING POST-CLOSURE 12
7.1.1 Method of Analysis 13
7.1.2 Description and Function of Diffusive Barrier 13
7.1.3 Failure Mechanism of a Diffusive Barrier 13
7.1.4 Summary of Analysis of the Diffusive Barrier Performance 15
7.1.5 Results of the Analysis of Diffusive Barrier Performance 15
7.2 EVALUATION OF THE GETTER BENEATH THE WASTE PACKAGE FEATURE 18
7.2.1 Sorption Process Mechanism 18
7.2.2 Geochemical Factors that Influence the Transport Properties and Sorption Behavior of Radionuclides 18
7.2.3 Selection Criteria for Getter Material 19
7.2.4 Potential Getter Materials 19
7.2.5 Suitability of the LANL Recommended Materials for Getter 20
7.2.6 Previous Sorption Experiments 23
7.2.7 Effects of Percolation on the Getter Barrier During Post-Closure 24
7.2.8 TSPA Results on the Performance of Two Getter Placement Configurations .. 32
7.2.9 Chemical Interactions that Affect Performance of the Getter Materials 36
7.2.10 Rationale for Thickness of Apatite Layer 38
7.3 THERMAL EFFECTS ON THE GETTER DURING POST-CLOSURE 40
7.3.1 The Effects of the Getter on Temperature of the Waste Packages 41
7.3.2 The Effect of Heating from Waste Packages on Getter Behavior 42
7.4 SEISMIC EFFECTS ON THE DIFFUSIVE BARRIER AND GETTER DURING POST-CLOSURE 42
7.4.1 Seismic Loading of the Diffusive Barrier and Getter 42
7.5 PLACEMENT METHODOLOGY FOR THE TWO GETTER CONFIGURATIONS 43
7.5.1 Placement Methodology for Case 1 and Case 2 Getter Configurations 43
7.5.2 Dust Control Measures 44

8. CONCLUSIONS 44

APPENDIX A EVALUATION CRITERIA QUESTIONS FOR THE DIFFUSIVE BARRIER AND GETTER UNDER THE WASTE PACKAGE FEATURES A-1
APPENDIX B ENVIRONMENTAL CONSIDERATIONS ASSOCIATED WITH THE DIFFUSIVE BARRIER AND GETTER FEATURES B-1
APPENDIX C RATIONALE FOR DETERMINING THE NUMBER AND SIZE OF FOOTINGS AND REQUIRED COMPACTION DENSITY OF GETTER SYSTEM MATERIALS C-1

FIGURES

Page

1. Diffusive Barrier Configuration 14
2. Breakthrough for One Dimensional Advection/Dispersion/Diffusion through a Diffusive Barrier 16
3. Contaminant Transport Dominated by Diffusion 16
4. Influence of Barrier Length on Performance of the Invert 17
5. Case 1 Getter Configuration 25
6. Case 2 Getter Configuration 26
7. Breakthrough of Np-237 through Apatite Getter- (Case 1 Getter Configuration - 1.2 m Thick Layer of Apatite) 29
8. Breakthrough of Tc-99 through Apatite Getter (Case 1 Getter Configuration - 1.2 m Thick Layer of Apatite) 30
9. Breakthrough of Np-237 through Various Materials (1.2 m Thick Layer) 31
10. Breakthrough of Np-237 and Tc-99 for a Diffusive/Getter Barrier (1.2 m Thick Layer) 31
11. Case 1 Getter Configuration (Thick Layer of Apatite) Dose Rate Results to 10,000 Years 33
12. Case 1 Getter Configuration (Thick Layer of Apatite) Dose Rate Results to 1,000,000 Years 34
13. Case 2 Getter Configuration (Thin Layer of Apatite) Dose Rate Results to 10,000 Years 35
14. Case 2 Getter Configuration (Thin Layer of Apatite) Dose Rate Results to 1,000,000 Years 36

TABLES

Page

1. Design Details for Case 1 and Case 2 Getter Placement Configurations
2. Distribution Coefficients for Neptunium and Technetium on Apatite 4
3. Candidate Getter Material 20
4. Minimum Depth of Getter Required to Adsorb Entire Inventory of Np or Tc, 25 °C 38
5. Minimum Depth of Getter Required to Adsorb Entire Inventory of Np or Tc, 60 °C 39

A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages A-10

1. PURPOSE

This technical document assesses the potential of the diffusive barrier and getter features to enhance the post-closure performance of the Viability Assessment (VA) Reference Design. In previous studies, the Total System Performance Assessment (TSPA) (DOE 1998b, Volume 3, Section 5.5.6) evaluated the safety strategy of radionuclide retardation from the EBS. Their studies were limited in that they evaluated only the effects of the concrete invert on delaying the release of radionuclides to the accessible environment. The effects of other materials were not considered. The results of their studies showed that the peak annual dose rate at the accessible environment with sorption on the concrete invert were not significantly different from the peak dose at the accessible environment without sorption credit on the concrete invert. Therefore, based on these limited studies they concluded that this safety strategy is of low significance to post-closure repository performance (DOE 1998b, Volume 3, Sections 5.5.6 and 6.4).

CRWMS M&O 1998f provides a description of design feature #16, diffusive barrier, and design feature #17, getter. This study examines the effect that diffusive material and chemically reactive material (getter) would have on reducing contaminant transport due to the mechanisms of diffusion and sorption respectively. Therefore, it is expected that these two features could be moderately important to post-closure performance. Preparation of this evaluation will be in accordance with the technical document preparation plan (TDPP), CRWMS M&O 1998m.

1.1 OBJECTIVE

The objective of this technical document on the design features diffusive barrier and getter under waste packages is to evaluate those aspects which have the potential for enhancing the design performance of the VA design and which are directly related to the key attributes of the repository safety strategy. To achieve this objective, these features will be evaluated against the evaluation criteria (CRWMS M&O 1998j).

1.2 SCOPE

This evaluation will use existing documents to identify and describe those aspects which impact upon the evaluation criteria described below. The inclusion of the features in the VA Reference Design will be evaluated against the VA Reference Design. The scope of this evaluation covers the performance assessment of the diffusive barrier and getter beneath the waste packages features, the behavior characteristics of such invert materials, and their constructability and cost assessment evaluation. Evaluation of these features will include the following:

- Analyze the thermal, hydrological and chemical effects on the behavior, stability and longevity of the diffusive barrier and/or getter materials due to intrusion of groundwater.
- Evaluate the effect ventilation has on potentially causing fine particulate to become airborne during invert material placement.
- Evaluate drift conditions and configurations to demonstrate the suitability of placing a diffusive barrier and/or getter in the invert. Barrier requirements may preclude incorporating the current invert design so that alternative designs may be developed.

- Evaluate against the evaluation criteria which are supplied by the LADS team.

1.3 BACKGROUND

Emplacement drift diffusive barrier and getter issues were discussed in *Engineered Barrier System Performance Requirements Systems Study Report,* (CRWMS M&O 1997a); the *Waste Isolation Study,* (CRWMS M&O 1997b) and other technical analyses and reports. The *Engineered Barrier System Performance Requirements Systems Study Report,* (CRWMS M&O 1997a) discusses the Los Alamos National Laboratory (LANL) experiment on the sorption of neptunium and technetium on apatite. The results for the 21 day experiment were obtained from LANL and are presented in 4.1.2. In the *Waste Isolation Study,* the thickness of apatite required for sorption of the entire inventory of neptunium was determined (CRWMS M&O 1997b, p. 3-26). None of the information presented in the *Waste Isolation Study* report was used for this technical document since more recent information was available. The *Waste Isolation Study* was based on the preliminary LANL work. The apatite thicknesses for the two getter configurations were assumed (4.3.2, 4.3.3) and a calculation titled, *Calculations for Sorption of Np and Tc in a Potential Adsorbing Apatite Getter Below a Waste Package* (CRWMS M&O 1999d) was done as a backcheck to ensure that the thicknesses chosen were appropriate.

2. QUALITY ASSURANCE

This design feature evaluation activity has been evaluated in accordance with QAP-2-0, *Conduct of Activities,* and has been determined to be quality affecting (CRWMS M&O 1998k) and subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) (DOE 1998a). The quality assurance controls are in accordance with NLP-3-18, *Documentation of QA Controls on Drawings, Specifications, Design Analyses, and Technical Documents.* Since the document is preliminary and conceptual in nature and will not be used for construction, procurement, or fabrication, the TBVs will only be identified and not be assigned tracking numbers. This document was prepared per QAP-3-5, Development of Technical Documents. Information will be exchanged in accordance with QAP-3-12, *Transmittal of Design Input* and NLP-3-27, *Engineering Calculations.*

3. METHOD

Both quantitative and qualitative analyses are used to evaluate the performance of the diffusive barrier and getter features.

The post-closure performance of the diffusive barrier and the getter is presented in the format of contaminant breakthrough curves (CRWMS M&O 1999a, Item 3). Summaries of the analyses that generated the contaminant breakthrough curves describe the effects of advection/dispersion/diffusion and sorption on the performance of the invert materials (diffusive barrier/getter). The post-closure performance of the two getter configurations is also presented in the format of radiological dose rates histories at the accessible environment. The radiological dose rate histories and their interpretation is extracted from CRWMS M&O 1998g.

CRWMS M&O 1999d provides a rationale for the thickness of apatite material that is necessary to sorb the complete inventory of radionuclides from a 21 PWR waste package. The results are used as a backcheck to the thicknesses of apatite and crushed tuff that are described in Section 7.2.5.2.

The evaluation criteria presented in CRWMS M&O 1998j are used to identify and evaluate the aspects of these two design features which have the potential to enhance the design performance of the VA Reference Design. The evaluation criteria questions will describe the features in terms of their post-closure performance, pre-closure performance, assurance of safety, engineering acceptance, construction, operations, and maintenance, schedule, cost, and environmental considerations. A rating system of 1 to 5 will be applied to each evaluation criteria question with the exception of the post-closure performance cost, schedule, and environmental consideration questions. A rating of one and two would indicate significant to moderate disadvantages, respectively, associated with these design features, a three would indicate equivalence to the VA design, a 4 and 5 would indicate moderate to significantly higher advantages, respectively, associated with these design features.

4. DESIGN INPUTS

This document is preliminary and conceptual in nature and will not be used for construction, procurement, or fabrication, the TBV's will be identified, but not assigned tracking numbers.

4.1 DESIGN PARAMETERS

4.1.1 Emplacement Drift Details for Case 2 Getter Configurations

Emplacement drift details for the Case 2 Getter Configuration are described below (TBV).

Table 1. Design Details for Case 2 Getter Placement Configuration

Design Details	Case 2	References Case 2
Outer Diameter of Waste Emplacement Drifts	5.5m	Emplacement drift diameter CRWMS M&O 1997c, p. 73.
Concrete Liner Thickness	200 mm	CRWMS M&O 1997c, p 56.
Distance from base of concrete invert to top of Concrete Invert	0.855 m to top of concrete invert	CRWMS M&O 1998e Attachment II p. 12 of 72, Figure II-3

4.1.2 Distribution Coefficients (K_d) for Neptunium (Np-237) and Technetium (Tc-95m) on Apatite

Sorption experiments were performed by Los Alamos National Laboratory (LANL) to obtain the K_d values for Np-237 and Tc-95m (CRWMS M&O 1998c, Item 2, pp.15 and 19) (TBV). Two sorption tests were done for each pH. Table 2 illustrates the distribution coefficients for neptunium and technetium on apatite (TBV). The values in the Avg. K_d column are the arithmetic mean of the two K_d values obtained for the two sorption tests at three weeks. The K_d values described in Table 2 are used throughout Sections 7.2.1, 7.2.5.1, 7.2.5.5, and 7.3.2.

Table 2. Distribution Coefficients for Neptunium and Technetium on Apatite

		25°C			60°C		
		Test 1	Test 2		Test 1	Test 2	
Radionuclides	pH	K_d (mL/g)	K_d (mL/g)	Avg.K_d (mL/g)	K_d (mL/g)	K_d (mL/g)	Avg.K_d (mL/g)
Neptunium (Np-237)	4	2030	1850	1940	2210	2530	2370
Technetium (Tc-95m)	4	0.132	0.362	0.247	2.25	2.44	2.345
Neptunium (Np-237)	6	1890	1720	1805	2970	2920	2945
Technetium (Tc-95m)	6	1.5	0.635	1.07	2.77	1.76	2.27
Neptunium (Np-237)	8	1990	2000	1995	606	3620	2113
Technetium (Tc-95m)	8	0.257	0.181	0.219	6.6	5.41	6.01
Neptunium (Np-237)	10	2080	2010	2045	3800	1420	2610
Technetium (Tc-95m)	10	0.209	0.137	0.173	8.16	8.15	8.16

4.1.3 Breakthrough Curves Pertaining to the Diffusive Barrier and Getter Evaluation

The basis for the breakthrough curves for the diffusive barrier and getter evaluation is the *Analysis of Advection/Dispersion/Diffusion/Sorption for the Invert* which is contained in *Scoping calculations for Engineered Barrier System Modeling and Analysis Support for the License Application Design Selection (LADS) for single backfill, the Richards Barrier, the diffusive barrier, and the getter barrier features* (CRWMS M&O 1999a, Item 3). Figures 2, 3, 4, 5, 6, 7, 8 on pp. 16 of 27, 17 of 27, 18 of 27, 22 of 27, 23 of 27, 24 of 27, 25 of 27, respectively, of Item 3 of CRWMS M&O 1999a are reproduced as Figures 2, 3, and 4 in Section 7.1.5 and Figures 7, 8, 9, and 10 in Section 7.2.7.4. The breakthrough curves are assumed to provide an assessment of the post-closure performance of the repository when a diffusive barrier (Section 7.1.5) or getter material (7.2.7.4) is placed under the waste packages (TBV).

4.1.4 Total System Performance Assessment Results of Two Getter Configurations

The assumed peak annual radiological dose rates at a distance of 20 km from the repository site, over the two time frames, up to 10,000 years and up to 1,000,000 years after repository closure, for the two getter configuration cases were determined in CRWMS M&O 1998g (TBV). Figures 1, 2, 3, and 4 in Attachment II on pp. II.2 of II.13, II.3 of II.13, II.4 of II.13, and II.5 of II.13, respectively, of CRWMS M&O 1998g were reproduced as Figures 13, 14, 11, and 12, respectively, in Section 7.2.8. The post-closure performance results are assumed to provide a basis for selecting one getter configuration over the other (Sections 7.2.8 and A.1).

4.1.5 Thermal Evaluation of the Getter Configurations

Thermal evaluation of the getter was documented in *Thermal Evaluations for Design Selection* (CRWMS M&O 1999h, Attachment V) (TBV). This assumption is used in Section 7.3.

4.1.6 Required Apatite Thickness to Sorb the Np-237 and Tc-99 From a 21 PWR Waste Package

The calculated apatite thicknesses required to sorb the entire inventory of Np and Tc from a 21 PWR Waste Package are contained in CRWMS M&O 1999d. They are used as a back check to confirm that the thickness of apatite layers for the two getter configurations, shown in Figures 5 and 6 in Section 7.2.7.2, are appropriate. Tables 5.4-4 and 5.4-5, from CRWMS M&O 1999d, p.27 of 33, are reproduced as Tables 4 and 5 in Section 7.2.10.1.

4.1.7 Cost Estimate for the Two Getter Configurations

Cost estimate for the two getter configurations is provided in *Design Feature (DF) 16 & 17 - Diffusive Barrier and Getter Under Waste Package* (CRWMS M&O 1999b, Item 1, pp. 1 of 5 through 5 of 5)(TBV). Case 1 with the 6.5 m drift is estimated to cost $1.4 billion (TBV). The Case 2 estimated cost is $ 1.2 billion (TBV).

4.2 DESIGN CRITERIA

4.2.1 Use of Materials That Do Not Degrade Performance of the Waste Packages.

The subsystems which contact the waste packages following emplacement shall use materials which do not degrade the performance of the waste packages (CRWMS M&O 1998a, Vol. I, Section 1.2.1.15, p.9 of 19). This criterion is addressed in Appendix A, Table A-1.

4.2.2 The Ex-Container System Limiting Microbial Activity

The system shall limit microbial activity to protect the material integrity of the waste package (CRWMS M&O 1998a, Vol. I, Section 1.2.1.17, p.9 of 19). This criterion is addressed in Appendix A, Table A-1.

4.3 ASSUMPTIONS

4.3.1 Getter Barrier System

The getter barrier system is a two component system. It consists of two layers of gravel-sized crushed tuff and a layer of sorptive silt-sized getter material (apatite). To provide a stable foundation for the waste package the getter material is surrounded by a coarse layer of gravel - sized crushed tuff such that any water that flowed into the drift would be drawn into the silt-sized apatite. The apatite layer beneath the crushed tuff layer is located directly below the waste package so that radionuclide release would flow into the getter material. The type of materials to be used are preliminary and are TBV. This assumption is used in Section 7.2.7.2 and throughout Section 7.5.

4.3.2 Thickness of Getter System Materials Unconstrained By VA Emplacement Drift Diameter (Case 1)

Crushed tuff and apatite layer thicknesses for Case 1 were chosen to provide a better understanding of the impact of increasing the barrier thickness and the impact of increasing the number of available sorption sites on radionuclide migration through the barrier. In addition, the layer thicknesses were selected so that the additonal exavation costs for a larger drift needed to accommodate the getter system materials and a non-carry over gantry , could be minimized. The thickness of each crushed tuff layer is 0.5 m (TBV). The thickness of the apatite layer is 1.2 m (TBV). The total thickness of the getter system materials is 2.2m (TBV). This assumption is used in Sections 7.2.7.2, and 7.5.

4.3.3 Thickness of Getter System Materials for Case 2

The following paragraph describes the maximum thickness of the getter system materials that can be accommodated by the VA emplacement drift diameter, while at the same time provide a layer of sorptive material with the intention of delaying radionuclide migration through the barrier. The thickness of the getter barrier system for Case 2 is limited to the depth of the concrete invert. If the materials rise above the top of the invert they will spill out onto the rail. Therefore, in Case 2, the material thicknesses for each crushed tuff layer and the apatite layer are

0.1 (TBV) and 0.3 m (TBV) respectively, for a total thickness of 0.5 m (TBV). This assumption is used in Sections 7.2.7.2, and 7.5.

4.3.4 Emplacement Drift Diameter of Case 1 Getter Configuration

To accommodate the Case 1 getter configuration described in Assumption 4.3.2; and to provide sufficient clearance for a non-carry over gantry, so that additonal excavation costs could be kept to a minimum, an emplacement drift diameter of 6.5 m (TBV) was selected. This assumption is used in Section 7.5.

4.3.5 Rail and Ties for Case 1 Getter Design

The top layer of the getter barrier system for Case 1 is higher than the top of the concrete invert. Therefore, a new rail system will have to be installed on top of the final layer of crushed tuff. This assumption is used in Sections 7.2.7.2 and 7.5.1.

4.3.6 Nominal Allowable Bearing Pressure for Medium to Stiff Compacted Silt

A nominal allowable bearing pressure of 143,600 N/m^2 (3 kips per square ft or 3000lbs/ft^2) for medium to stiff compacted silt is assumed for the getter barrier system (ASCE 1993, p.37). No distinction is made between the gravel-sized crushed tuff layers and the silt-sized apatite layers in terms of selecting the nominal allowable bearing pressure. The nominal allowable bearing pressure assumed corresponds to the weakest material of the getter system barrier, namely the silt. Therefore, using this nominal allowable bearing pressure conservatively estimates the size of footing necessary to support the heaviest waste package. The bearing pressure of the footing must not exceed the nominal allowable bearing pressure of the compacted silt below. This assumption is used in Appendix C.

4.3.7 Mass and Dimensions of Heaviest Waste Package

The mass of the heaviest waste package (large Naval SNF canister) is 83,000 kg (CRWMS M&O 1998b, EBDRD 3.7.1.J.2) (TBV). The maximum external dimensions of this waste package are 2.0 m in diameter, 6.2 m long (CRWMS M&O 1998b, EBDRD 3.7.1.J.1) (TBV). This assumption is used in Appendix C.

4.3.8 Kd values for Tc-95m used as proxy for Kd values for Tc-99

The chemical behavior of technetium does not depend on the isotopic weight but on the atomic number, therefore, the K_d values for Tc-95m are used for Tc-99. This assumption is used in Sections 7.2.1 and 7.2.7.3.

4.3.9 Interim Post-closure Performance Measure

The expected annual dose to an average individual in a critical group living 20 km from the repository should not exceed 25 mrem from all pathways and all radionuclides during the first 10,000 years after closure (CRWMS M&O 1998b, p. 3-47) (TBV). This assumption is used in Section 7.2.8.

4.3.10 Concrete Liner Used in the Case 1 Emplacement Drift

As with the VA emplacement drift design, a 200 mm concrete liner (TBV) will be used with the 6.5 m diameter emplacement drift (TBV). This assumption is used in Section 7.2.7.2.

4.3.11 Top of Concrete Measurement for Case 1 Getter Configuration

The distance from the base of the concrete invert to the top of the concrete invert is 0.855 m. It is the summation of the 0.542 m and 0.313 m dimensions taken from VA emplacement drift invert that is described in CRWMS M&O 1998e, Attachment II, p.II-12 of II-72, Figure II-3. This assumption is used in 7.2.7.2.

4.3.12 Contribution of Concrete to the Post-closure Performance of the Diffusive Barrier or Getter Features

Due to thermal effects the concrete invert is expected to be cracked at the time of waste package breach. The concrete is inert with respect to the contribution, if any, of the diffusive barrier or getter post-closure performance. This assumption is used in Sections 7.1.4 and 7.2.7.3.

4.3.13 No Adsorption of Colloids onto the Apatite

There is no data on the adsorption of either technetium or neptunium colloids onto apatite. Therefore, assuming that there is no adsorption of these radionuclide colloids onto the apatite is a conservative assumption. This assumption is used in Section 7.2.9.3.

4.4 CODES AND STANDARDS

Not Used.

5. REFERENCES

ASCE (American Society of Civil Engineers) 1993. *Bearing Capacity of Soils.* New York, New York: ASCE Press. TIC: 241549.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1997a. *Engineered Barrier System Performance Requirements Systems Study Report.* BB0000000-01717-5705-00001 REV 02. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970929.0316.

CRWMS M&O 1997b. *Waste Isolation Study.* B00000000-01717-5705-00062 REV 00/DCN 1. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980513.0131.

CRWMS M&O 1997c. *Repository Subsurface Layout Configuration Analysis.* BCA000000-01717-0200-00008 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971201.0879.

CRWMS M&O 1997d. Not Used.

CRWMS M&O 1997e. *Materials for Emplacement Drift Ground Support.* BCAA00000-01717-0200-00003 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19971029.0493.

CRWMS M&O 1998a. *Ex-Container System Description Document.* BCA000000-01717-1705 00019 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981117.0424.

CRWMS M&O 1998b. *Controlled Design Assumptions Document.* B00000000-01717-4600-00032 REV 05. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980804.0481.

CRWMS M&O 1998c. *Design Input Transmittal for the Evaluation of the Getter Under the Waste Package (WP) License Application (LA) Reference Design Feature.* SSR-NEP-99044.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981207.0325.

CRWMS M&O 1998d. *Getter Material Properties.* B00000000-01717-0210-00035 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981123.0249.

CRWMS M&O 1998e. *Emplacement Drift Invert Structural Design Analysis.* BBDC00000-01717-0200-00001 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980625.0366.

CRWMS M&O 1998f. *Interoffice Correspondence Initial List of Design Features and Alternatives for LA Initial Design Selection.* LV.LRD.RDS.08/98-007. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980909.0036; MOL.19980909.0038.

CRWMS M&O 1998g. *Design Input Transmittal RIP Output for Design Feature (DF) #17 (Apatite Getters).* Input Tracking No.: SSR-PA-99001.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990216.0045.

CRWMS M&O 1998h. *Design Input Transmittal for Diffusive Barrier and Getter Features Beneath the Waste Package (WP) for the License Application (LA) Reference Design Feature.* Input Tracking No.: SSR-SEI-99005.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990329.0244.

CRWMS M&O 1998i. Not used.

CRWMS M&O 1998j. *Design Input Request for the Repository Design Selection Process.* Input Tracking No.:LAD-XX-99018.R. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981221.0202.

CRWMS M&O 1998k. *Activity Evaluation for Design Features for LA Design Selection-Subsurface Repository (FY99 WP# 12012382M1).* Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981130.0400.

CRWMS M&O 1998l. Not used.

CRWMS M&O 1998m. *Technical Document Preparation Plan (TDPP) for VA Reference Design Feature Evaluation #16 & 17:Diffusive Barrier and Getter Under Waste Packages.* B00000000-01717-4600-00127 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990519.0165.

CRWMS M&O 1998n. Not used.

CRWMS M&O 1998o. *Near-Field/Altered-Zone Models Report.* UCRL-ID-129179. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980630.0560.

CRWMS M&O 1999a. *Design Input Transmittal from EBS Performance Modeling for Scoping Calculations for Engineered Barrier System Modeling and Analysis Support for the License Application Design Selection (LADS) for Single Backfill, the Richards barrier, the Diffusive Barrier, and the Getter Barrier features.* Input Tracking No.: SSR-EBS-99171.Ta. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990505.0304.

CRWMS M&O 1999b. *Design Input Transmittal from Project Planning & Control for Design Features 16 and 17.* Input Tracking No. SSR-PPC-99203. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990428.0126.

CRWMS M&O 1999c. *Design Input Request for LADS Phase I Confidence Assessments.* Input Tracking No.: LAD-XX-99018.Ra. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990217.0222.

CRWMS M&O 1999d. *Calculations for Sorption of Np and Tc in a Potential Adsorbing Apatite Getter Below a Waste Package.* BBA000000-01717-0210-00034 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990319.0351.

CRWMS M&O 1999e. *Design Input Transmittal for NLP-3-27 Calculation for Three Volumetric Flow Rates, Calculations for Sorption of Np and Tc in a Potential Adsorbing Apatite Getter Below a Waste Package Sorption of Specified Radionuclides.* Input Tracking No.: SSR-WP-99007.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990413.0123.

CRWMS M&O 1999f. *Design Input Transmittal for Pre-Closure Performance, Design Feature (DF) #16 (Diffusive Barrier Under the Waste Package) & Design Feature (DF) #17 (Getter Under the Waste Package).* Input Tracking No.: SSR-SEI-99003.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990310.0060.

CRWMS M&O 1999g. *Design Input Transmittal Attached is the (MGR) System Analysis Inputs to the Evaluations of Design Feature (DF) #16, Diffusive Barrier Under the Waste Package (WP) and Design Feature (DF) #17, Getter Under the Waste Package (WP), for the License Application Design Selection (LADS). The Inputs Pertain to Performance Confirmation Implications of the Design Feature.* Input Tracking No.: SSR-SEI-99004.T. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990216.0043.

CRWMS M&O 1999h. *Thermal Evaluation for Design Selection.* BBAA00000-01717-0210-00013 REV 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981209.0398.

DOE (United States Department of Energy) 1998a. *Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program.* DOE/RW-0333P REV 08. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19980601.0022.

DOE 1998b. *Viability Assessment of a Repository at Yucca Mountain* DOE/RW-0508. Washington, D.C.: Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0028. MOL.19981007.0029. MOL.19981007.0030.

Fetter, C.W. 1993. *Contaminant Hydrogeology.* New York, New York: Macmillan Publishing Co. TIC: 240691.

Forsberg, C.W. and Pope, R.B. 1995. *Use of Depleted-Uranium Borosilicate Glass as Backfill Material Inside LWR Spent Nuclear Fuel Repository Waste Packages.* Oak Ridge, Tennessee: Oak Ridge National Laboratory. ACC: HQO.19950127.0022.

Lessing, P.A. 1995. *Development of DU-AGG (Depleted Uranium Aggregate).* INEL-95/0315. Idaho Falls, Idaho: Lockheed Idaho Technologies Company. TIC: 241167.

Jury, W.A., Gardner, W.R., and Gardner, W.H. 1991. *Soil Physics, Fifth Edition.* New York, New York: John Wiley and Sons, Inc. TIC: 241619.

Roberts, W.L., Rapp, G.R., and Weber, J. 1974. *Encyclopedia of Minerals.* New York, New York: Van Nostrand Reinhold Company. TIC: 240996.

Triay, I.R., Mitchell, A.J., Ott, M.A. 1991. "Radionuclide Migration as a Function of Mineralogy". *High Level Radioactive Waste Management: Proceedings of the Second Annual International Conference Las Vegas, Nevada. April 28-May 3, 1991 pp. 494-498.* La Grange Park, IL: American Nuclear Society, Inc. TIC: 221953.

Triay, I.R., Meijer, A., Conca, J.L., Kung, K.S., Rundberg, R.S., Strietelmeier, E.A. 1996. *Summary and Synthesis Report on Radionuclide Retardation for the Yucca Mountain Site Characterization Project Milestone 3784.* Los Alamos, New Mexico: Los Alamos National Laboratory. ACC: MOL.19961231.0099.

6. USE OF COMPUTER SOFTWARE

Not Used.

7. DIFFUSIVE BARRIER AND GETTER EVALUATION

The diffusive barrier (DF #16) and getter (DF #17) are design features that could be moderately important to post-closure performance. If the diffusive Barrier (DF#16) and getter (DF#17) under the waste package system, or in combination with other features, contribute to a lower peak dose at the accessible environment, 10,000 years after emplacement, than the peak dose predicted for the VA Reference design, these features may be included in the LA design. This design enhancement may be favorable to the Nuclear Regulatory Commission (NRC's) acceptance of the LA design by providing assurance that regulatory compliance can be achieved through the use of a defense in-depth design approach.

The TSPA-VA (DOE 1998b, Volume 3, p. 3-1, Table 3-1) applied models which included the near field geochemical environment model and the thermal-hydrological model, to predict the probable behavior of the repository system over time. The TSPA-VA considered the potential for radionuclide release from the repository system and its transport 20 km downgradient from the repository, where an average individual would withdraw water from a hypothetical well (accessible environment). Dose rates (mrem/yr) vs time profiles were predicted for the most important radionuclides in different time periods (DOE 1998b, Volume 3, p. 4-23, Figure 4-12). In the first 10,000 years Tc-99 and I-129 are the important radionuclides, up to 100,000 years Tc-99 and Np-237 are the major radionuclides, and within 1,000,000 years Np-237 and Pu-242 are the major radionuclides.

The past experiments whose Kd values are presented in CRWMS M&O 1998d, Attachment I have not fully characterized the hydrological and chemical properties of potential diffusive barrier and getter materials in the expected geochemical-thermal-hydrological environment at Yucca Mountain. The experiments were not performed at the percolation rates nor at the temperatures expected in the proposed repository. The interactions occurring between the groundwater chemistry, the getter or diffusive barrier materials and the radionuclides, are difficult to reproduce in a laboratory setting. Consequently, the experiments, (CRWMS M&O 1998d, Attachment I) can not definitively support the selection of one material over another to perform the function of a getter or diffusive barrier as no single material exists that can significantly retard or prevent migration of important radionuclides such as neptunium and technetium (See Attachment I of CRWMS M&O 1998d).

The following sections evaluate the hydrological and chemical properties of candidate diffusive barrier and getter materials, and the groundwater, thermal and seismic impacts on the materials' post closure performance. In addition, the placement methodology, associated with inclusion of a diffusive barrier or getter to the LA design, is evaluated.

7.1 EFFECTS OF PERCOLATION ON THE DIFFUSIVE BARRIER DURING POST-CLOSURE

Current information is available for describing and evaluating the spatial variability of groundwater percolation fluxes (CRWMS M&O 1999a, Item 3, Attachment III, p.1 of 4) for the six repository regions over three different climate conditions: dry (DRY), long term average (LTA), and superpluvial (SP), which are defined in DOE 1998b, Volume 3, A-14, A-25, and A-39, respectively. The effects of the variable groundwater percolation fluxes on the performance of the invert material under present DRY climate conditions, LTA and SP events will be presented in this technical document.

7.1.1 Method of Analysis

The one-dimensional advection/dispersion/diffusion equation for contaminant transport is contained in CRWMS M&O 1999a, Item 3 p. 4 of 27. It is used to evaluate the effects of advection, hydrodynamic dispersion, and diffusion for the diffusive barrier.

7.1.2 Description and Function of Diffusive Barrier

As radionuclides are released from the waste package, the contaminant transport is governed by advection/dispersion/diffusion in an unsaturated medium. The diffusive barrier may consist of a single material or multiple materials emplaced below the waste packages. The diffusive barrier materials are envisioned to be a media in which diffusion is the dominant mass transport mechanism. The breakthrough of contaminant transport through the diffusive barrier depends on this mechanism.

If the transport of radionuclides through the diffusive barrier were dominated by diffusion then the time to breakthrough of radionuclides would increase compared to the breakthrough time for advection dominated transport. The diffusive barrier materials emplaced (fine-grained sand and crushed tuff) are considered to be non-sorbing. Therefore, retardation of radionuclide transport through sorption mechanisms is excluded. In this technical document, one placement configuration for the diffusive barrier is evaluated. It consists of two materials, namely gravel sized crushed tuff and fine-grained sand. As with the Case 2 getter configuration, the thickness of the crushed tuff layers and sand layers are 0.1 m and 0.3 m ,respectively. These materials are placed in continuous layers, extending along the length of drift used for emplacement. Therefore, there are no piers used with this design. The placement configuration for the diffusive barrier is illustrated in Figure 1.

7.1.3 Failure Mechanism of a Diffusive Barrier

The function of the diffusive barrier is to act as a barrier to mass transfer of radionuclides so that diffusion dominates. If transport of radionuclides through the invert is dominated by advection-dispersion rather than diffusion, then the diffusive barrier will not enhance the performance of the repository through impeding the migration of radionuclides out of the EBS.

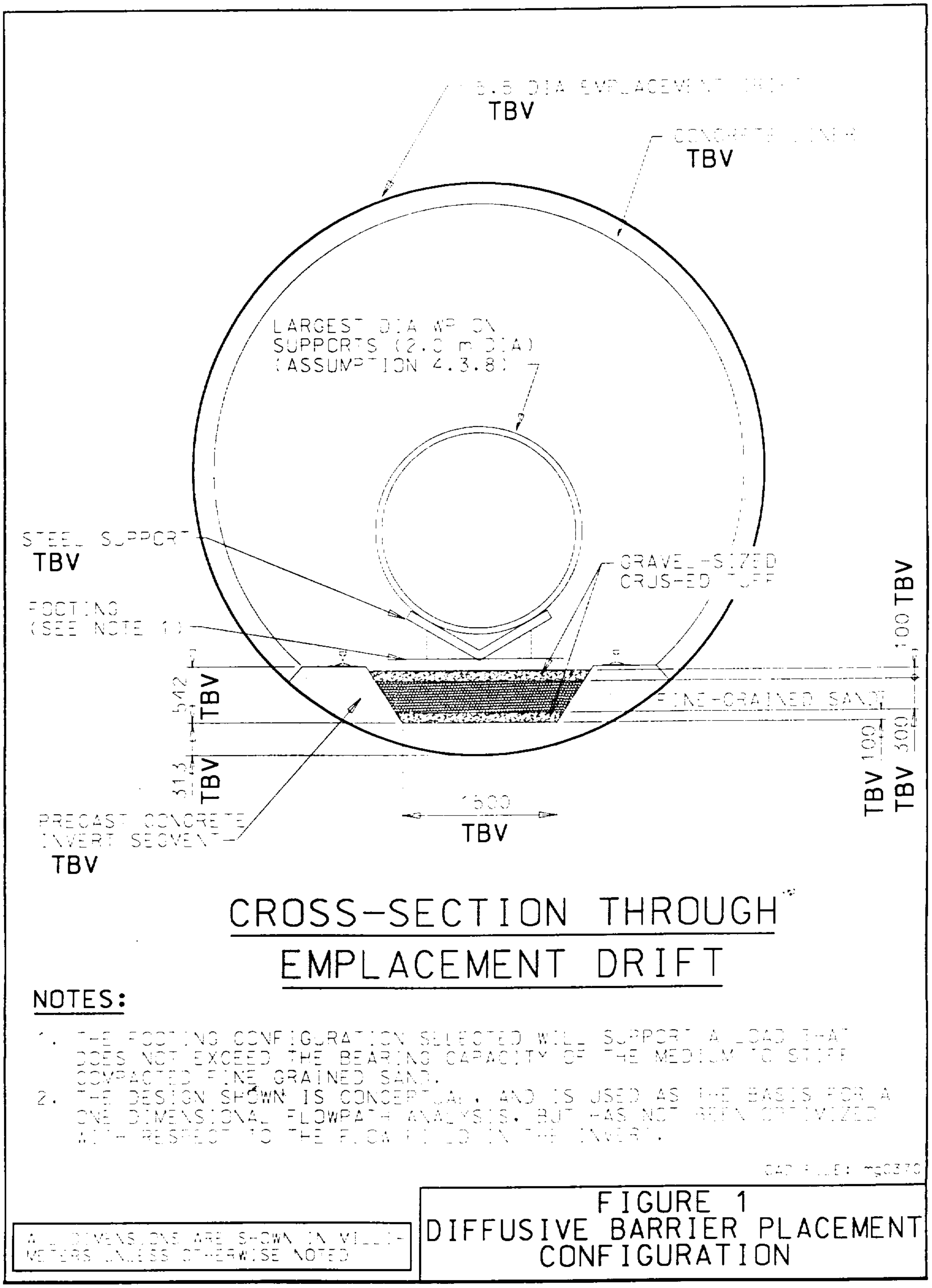

Figure 1. Diffusive Barrier Configuration

7.1.4 Summary of Analysis of the Diffusive Barrier Performance

The one-dimensional advection/dispersion/diffusion equation (CRWMS M&O 1999a, Item 3, p. 4 of 27) is used to evaluate the effects of advection/dispersion/diffusion on radionuclide migration through a porous medium such as a fine-grained sand. The fine-grained sand is evaluated as to its ability to increase the breakthrough time from the EBS, via transport dominated by molecular diffusion. The concrete invert is assumed to be cracked at the time of waste package breach and not provide a barrier to radionuclide migration from the EBS (4.3.12).

The following describes how the advection/dispersion/diffusion equation is utilized to generate the contaminant breakthrough curves for a diffusive barrier (See Figures 2, 3 and 4) (4.1.3). The waste package flow rates determined in CRWMS M&O 1999a, Item 3, Attachment III, pp.3 of 4 and 4 of 4 are used to calculate the volumetric moisture content and pore water velocities (average linear velocities) for the diffusive barrier (fine-grained sand). The above mentioned are determined for the six repository regions, which are defined in CRWMS M&O 1998o, p.3A-54, and for the three different climate conditions: dry (DRY), long term average (LTA), and superpluvial (SP), which are defined in DOE 1998b, Volume 3, A-14, A-25, and A-39, respectively. The volumetric moisture content and the pore water velocities for the fine-grained sand are presented in CRWMS M&O 1999a, Item 3, Attachment I, pp. 7 of 10 and 8 of 10, respectively. The mean volumetric moisture content for the DRY, LTA and SP climates are presented in CRWMS M&O 1999a, Item 3, Attachment I, p. 8 of 10.

Then, using the Millington-Quirk tortuosity relation (CRWMS M&O 1999a, Item 3, p.5 of 27) the soil/liquid diffusion coefficient for the three climates can be determined by multiplying the binary diffusion coefficient by a ratio of the mean volumetric moisture to the porosity. The hydrodynamic dispersion coefficient is determined by multiplying the pore water velocity by the dispersivity (CRWMS M&O 1999a, p.6 of 27). A dispersivity of 10 cm is selected based on engineering judgement, since, in the field, dispersivity ranges from 5-20 cm (Jury et al, 1991, p.222). The ratio of the hydrodynamic dispersion coefficient to the soil/liquid dispersion coefficients are then determined (CRWMS M&O 1999a, Item 3, Attachment I, p.9 of 10). Ratios greater than one indicate that dispersion is dominant. This is the case for the DRY, LTA, and SP climates. The dispersion/diffusion coefficient for sand for the three climates is calculated (CRWMS M&O 1999a, Item 3, Attachment I, p.10 of 10) by dividing the effective dispersion/diffusion coefficient, which is the summation of the hydrodynamic dispersion coefficient and the soil/liquid diffusion coefficient (CRWMS M&O 1999a, Item 3, p.5 of 27), by the mean volumetric moisture content. From the above information, the contaminant breakthrough curves for a diffusive barrier (fine-grained sand) are generated.

7.1.5 Results of the Analysis of Diffusive Barrier Performance

The short breakthrough times presented in Figure 2 (4.1.3) show that because of the predominance of advection-dispersion, the diffusive barrier feature alone would not be effective in retarding migration of radionuclides. However, if the feature were combined with other features that reduced the potential for advection, the pore water velocity (average linear velocity) would be reduced and there would be a substantial delay in the breakthrough of radionuclides. The hydrodynamic dispersion coefficient which equals the dispersivity times the pore water velocity is also reduced resulting in the effective dispersion/diffusion coefficient equaling the soil/liquid diffusion coefficient. Figure 3 (4.1.3) illustrates these combined effects on the breakthrough of radionuclides through the diffusive barrier.

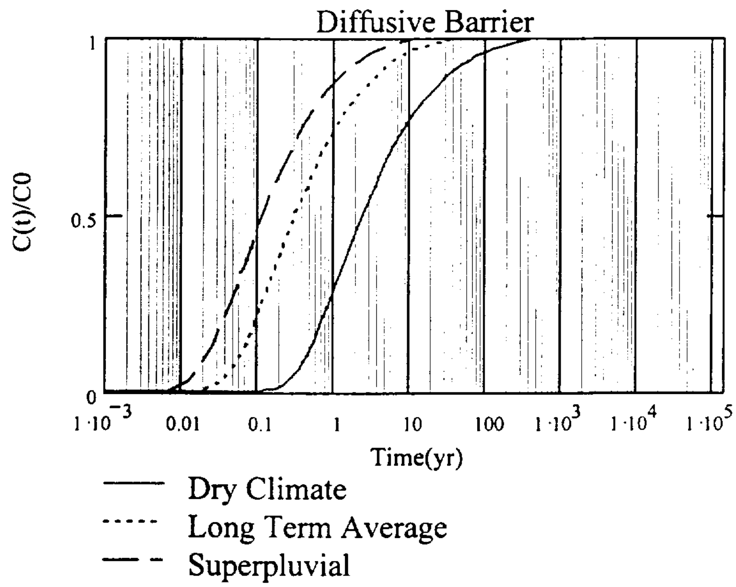

Figure 2. Breakthrough for One Dimensional Advection/Dispersion/Diffusion through a Diffusive Barrier

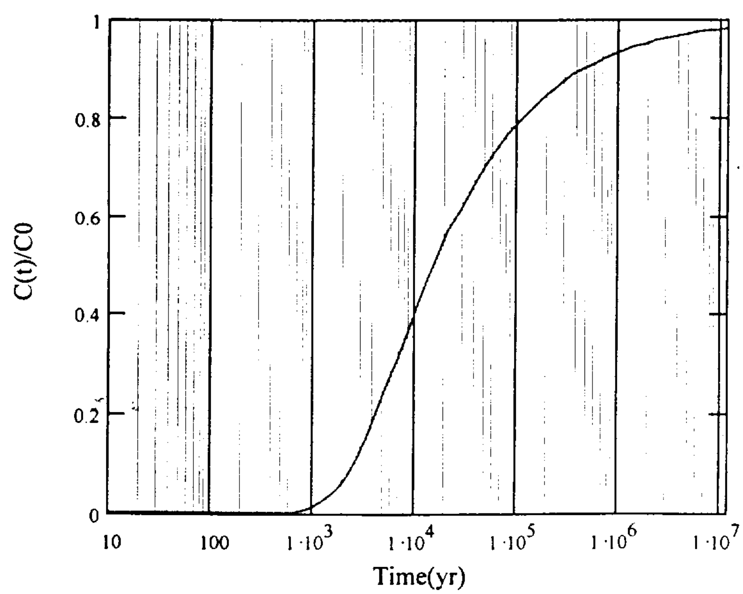

Figure 3. Contaminant Transport Dominated by Diffusion

Figure 4 (4.1.3) illustrates the influence of increasing the barrier length with the result that pore volumes (Lθ) must flow through the barrier before breakthrough takes place. Increasing the barrier length (thickness of diffusive barrier materials) appears to have little effect on increasing the time to breakthrough.

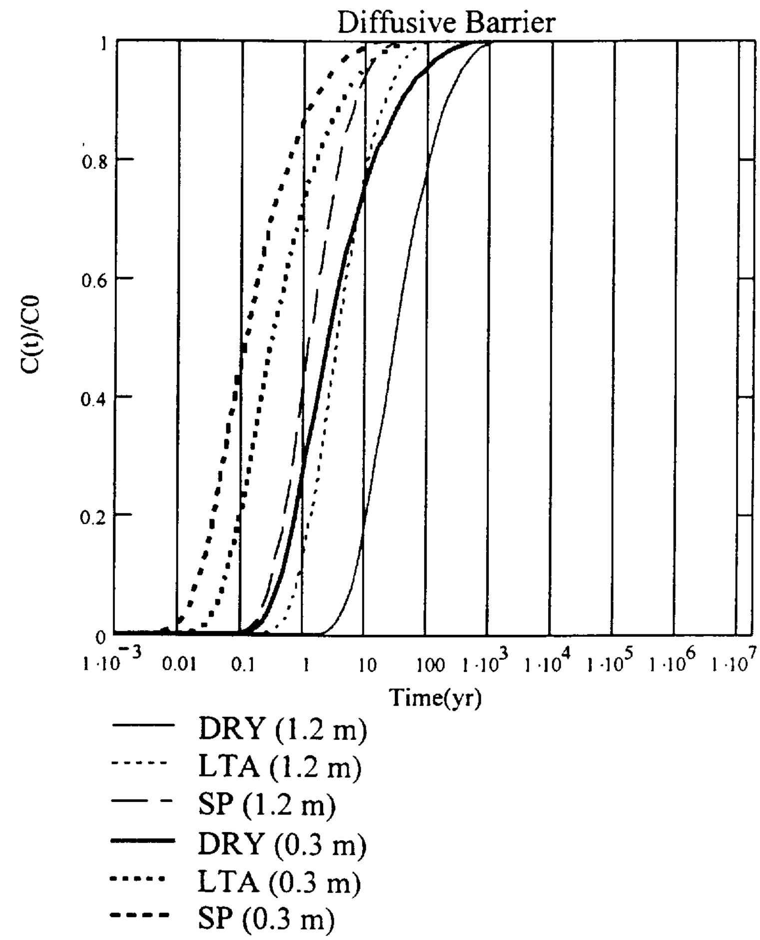

Figure 4. Influence of Barrier Length on Performance of the Invert

The influence of barrier thickness depicted in Figure 4 (4.1.3) shows that the thickness has little effect when the advective-dispersion flow dominates.

7.2 EVALUATION OF THE GETTER BENEATH THE WASTE PACKAGE FEATURE

7.2.1 Sorption Process Mechanism

Sorption processes (Fetter 1993, p.117) include adsorption, chemisorption, ion exchange and absorption. Adsorption is the process by which a solute adheres to a solid surface. Cations may be attracted to the region close to a negatively charged clay-mineral surface and held by electrostatic forces. Chemisorption occurs when the solute is incorporated on a sediment, soil or rock surface by chemical reactions. Cation exchange is the replacing of some positive ion in the interior of a single crystal of a solid by another positive ion or ions. Anion exchange can occur at positively charged sites on iron and aluminum oxides or on the fractured edges of clay minerals. Absorption occurs when the invert material is porous so that radionuclides can diffuse into the pore spaces and be retrained within the pores.

In the analysis of the getter material, no attempt will be made to distinguish among the various processes that contribute to sorption. The K_ds for Np-237 and Tc-95m on apatite measured by Los Alamos National Laboratory (LANL) will be used for this analysis (CRWMS M&O 1998c, Item 2, pp. 15, 19). The chemical behavior of Tc does not depend on the isotopic weight but on the atomic number, therefore the K_d values for Tc-95m were used for Tc-99 (4.3.8). The values for sorption coefficients reported from laboratory measurements reflect the relative partitioning of solute on the invert material, and in the J13 well water.

The sorption capabilities of a getter material are measured experimentally through batch sorption or column tests. The K_d values obtained in these experiments do not indicate by what specific mechanism sorption has occurred. The chemical relationship is between a concentration of radionuclides in solution and the number of adsorbing sites per unit area of solid. K_d can be expressed in a number of ways. However, it is often expressed in terms of the ratio of the mass of solute (radionuclide) (g) adsorbed per mass of sorbent (getter) (g) divided by the mass of solute (g) per volume of solution (H_2O) (mL). The resulting units for K_d are expressed in mL (or cm^3) of solution per g of solid (getter).

7.2.2 Geochemical Factors that Influence the Transport Properties and Sorption Behavior of Radionuclides

7.2.2.1 Water chemistry

Water chemistry influences the sorption behavior and the solubility of radionuclide compounds. The main parameters that could significantly influence transport properties and sorption behavior are the pH (a measure of the concentration of acid or alkali), the Eh (a measure of oxidation potential) of the solution, and complexing agents such as carbonates that combine with radionuclide ions and change the solubility and sorption capability. Depending on speciation and solubility, metals may be more mobile at low pH and high pH. This may permit their transport out of the EBS. The expected range in pH within the repository is from 6.5 to 9.0 (very weakly acidic to mildly alkaline) (DOE 1998b, Volume 1, Section 2.2.5.3, p.2-68).

7.2.2.2 Incoming Gas

In the near-field geochemical environment model for incoming gas, gas composition is represented by the major gas constituents: steam(H_2O), oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2). Steam (or water vapor) is generated during the boiling period and affects the rate at which waste packages corrode. Carbon dioxide directly affects the pH of solutions (which affects waste form dissolution) and can strongly affect actinide complexes (increasing their dissolved concentrations). Finally, nitrogen generally comprises most of the air component of the gas and may serve as a nutrient source for microbial activity (DOE 1998b, Volume 3, Section 3.3.1.2, p.3-45).

7.2.3 Selection Criteria for Getter Material

To provide the best performance, the getter materials should possess as many of the following characteristics as feasible:

- High Sorption Capabilities – The higher the K_d value the greater the getter material's ability to sorb radionuclides.

- Insolubility – The getter materials should be relatively insoluble throughout a range of temperatures, and groundwater pH.

- Thermal stability under high temperatures – The getter materials should be chemically stable over a range of temperatures. The getter materials should not undergo any mineralogical changes with the elevated temperatures expected in the repository.

- Chemical stability – The getter materials should not degrade at elevated temperatures and over time to substances with a lower sorptive capability than the original getter material.

- Fine-grained sized material - Since K_d, expressed as mL/g, is a function of surface area, the getter materials' sorption capability can be enhanced if crushed to a fine-grained size material. This increases the surface area per gram of getter material hence, the number of available sorption sites per gram of getter material.

7.2.4 Potential Getter Materials

LANL has outlined a list of candidate getter materials (CRWMS M&O 1998c, Item 4, p.4) with their intended function and the major problems associated with their use. Table 3 of this technical document is based on LANL's table. Information that has been added or changed is denoted with an asterisk. Those materials with a listing of thermal instability under the disadvantages category will irreversibly change properties during the thermal phase. Those materials with a listing of chemical instability will irreversibly change properties as a result of chemical interaction with infiltrating water and/or other aspects of the system such as concrete interaction with carbon dioxide. All others materials are relatively stable with respect to temperature and chemistry.

Table 3. Candidate Getter Material

Getter Material	Intended Function	Disadvantages
Smectite clays	Adsorption, extremely low hydraulic conductivity	Thermal instability, unsaturated cracking
Depleted uranium	Neutron absorber	Carcinogenic dust, promotes competitive sorption *
Zeolites (or crushed zeolitic tuff)	Specific sorption of radionuclides	Thermal instabilities,
Calcite	Sorption of radionuclides, raise ionic strength	Uncertain lifetime, chemical instability
Lime	Raise ionic strength/immobilize colloids sorb CO_2	Short lifetime, chemical instability
Concrete	Raise ionic strength/immobilize colloids, sorb CO_2	Uncertain lifetime, chemical instability
Apatite sand (North Carolina phosphate) *	Immobilize U and Np	production uncertain
Basalt gravel	Reduction/immobilize Tc	Uncertain reactivity with Tc *
Pyroxene	Reduction/immobilize Tc	Uncertain reactivity with Tc *
Zero Valent Iron or magnetite (Fe_3O_4)	Reduction/immobilize Tc, sorb or co-precipitate other radionuclides	Unknown corrosion issues, chemical instability
Hematite) (Fe_2O_3) or Goethite (FeOOH) *	Sorb or co-precipitate other radionuclides	Thermal Instabilities *
Borax	Neutron absorber	Uncertain lifetime, chemical instability
Boehmite (AlOOH) *	Immobilize radionuclides	Uncertain performance

* Information that has been added or changed from the LANL table.

The aging of the getter materials with respect to sorption is a complex issue that has separate effects for each material and for each condition. However, those materials without a listing of chemical instability under the disadvantages category should not be significantly affected by waste package corrosion, changes in surface reactivities, or other long-term chemical effects.

The finer the getter material, the greater the surface area per gram and therefore the greater the number of available sorption sites per gram. Therefore, the getter materials would be emplaced with a grain-size equal to a silt or fine sand with a total porosity from 0.4 to 0.5 and with well-known unsaturated hydrologic properties (CRWMS M&O 1998c, Item 4, p.4).

Some materials are already silt-sized while others will have to be crushed or engineered to this form. Dry bulk densities depend upon particle densities and porosities. Wet bulk densities depend upon the water content but are considered at the residual for a silt or about 0.25 (CRWMS M&O 1998c, Item 4, p.4).

7.2.5 Suitability of the LANL Recommended Materials for Getter

The following discussion expands on the suitability of the candidate materials (CRWMS M&O 1999e, Item 2, pp. 1 through 4).

7.2.5.1 Smectite Clays

These swelling clays have very high capacity for absorbing water. As they do so, they swell to many times their original, more or less, dry condition and effectively reduce the permeability, or hydraulic conductivity, to very low values. On subsequent drying they are prone to cracking (i.e., forming mud cracks) which would provide preferential highly conductive pathways. In addition, the hydroxide ions that form part of their crystal structure will be driven off as water at sufficiently high temperature thereby irreversibly changing the chemical characteristics of the material. These clays are very fine grained and, consequently, possess a very high ratio of surface area to volume, which is closely related to their high capacity for adsorption of radionuclides. Smectites may take up ions from solution both by way of adsorption onto mineral grain surfaces and by ion exchange between crystallographic layers of the clay structure. Because the grain size is unlikely to be greatly affected by heating to temperatures anticipated in a repository, heating may have little effect on adsorption onto surfaces. However, the ability of ions to penetrate into the structure along the crystallographic layers may be destroyed by the heating. This would be of most importance for small ions, such as Cs^+, but large ions, such as NpO_2^+, may be little affected because they are unable in any case to penetrate very much along the layers. No definitive data were identified to answer these uncertainties.

7.2.5.2 Depleted Uranium Placed with a Getter Material

The placement of depleted uranium (DU) with the getter material is being considered due to the large quantity of depleted uranium held by the DOE. If DU were utilized in the repository it would help reduce the excess quantities of depleted uranium.

Another benefit associated with its use is that it may reduce the chances of a criticality situation occurring within the getter, once the waste packages breach, through isotope dilution and the sorption of neutrons produced during the radionuclide decay and competitive sorption between other radionuclides.

There are, however, a number of disadvantages associated with the use of DU in this feature. Firstly, if the DU is in the form of a metal it could react with the water to form UH_3, which is pyrophoric. Secondly, DU does not possess any chemically sorptive properties. Thirdly uranium released to solution from the DU could sorb onto getter sorption sites and prevent adsorption of Np-237 and other actinides.

If we consider that the DU is mixed with the getter material and placed at the time of construction of the emplacement drifts, water may be present in the drifts. This could result in the DU sorbing onto the getter, before the waste packages are even emplaced. This would render the getter material ineffective at the time the waste packages are breached.

If upon waste package breach there are still sorption sites remaining within the apatite, the DU may compete with the released radionuclides for these sites. The radionuclides that are not sorbed by the getter will be transported by water through the EBS without any retardation.

Another disadvantage associated with DU is the potential to impact workers' health and safety since alpha particles are emitted from this radioactive material. Placement of DU would necessitate workers wearing personal protective equipment to reduce skin contact and to the prevent inhalation of the carcinogenic uranium dusts.

7.2.5.3 Zeolites

These minerals share some of the characteristics of the smectites, except for swelling properties. Hence, sufficient heating (loss of hydroxyl water) may significantly change them, but adsorption may be little affected on the surfaces of mineral grains, which are often, but not always, very fine grained. For zeolites ion exchange takes place along structural channels in the crystals, rather than along layers, and again tends to be restricted to small ions. This capability may be lost upon heating.

7.2.5.4 Calcite

Calcite does exhibit significant adsorption for actinides (Triay et al, 1996, p. III 3-23). Pure water placed into contact with calcite will dissolve a small amount of the solid, thereby raising the ionic strength to a low value. Possibly this is high enough to cause coagulation of colloidal suspensions. However, in the repository the water dripping into the drift will most likely already have come to equilibrium with calcite in the overlying fractures with the consequence that no further increase in ionic strength will ensue from further contact with calcite. Thus, colloids mobilized within the waste package are unlikely to be coagulated by contact with calcite below the waste package. Calcite does persist for long times in geological environments, e.g., in limestones, but under suitable circumstances will dissolve with the formation of caverns or irregular (karst) surface topography. This slight solubility, i.e., chemical instability, would need further evaluation before calcite is accepted as a getter material. Temperatures in the repository are not expected to increase sufficiently to drive CO_2 off from the calcite.

7.2.5.5 Lime and Concrete

Lime, CaO, will react rapidly with water to form calcium hydroxide, the mineral portlandite ($Ca(OH)_2$). Subsequently, it will gradually react with atmospheric CO_2 or dissölved bicarbonate to form calcite. By the time a waste package breaches the exposed surface of any lime that was emplaced would, consequently, behave in the same way as would calcite. Essentially the same considerations apply to concrete, except that the initial rates of reaction are slower and the lime originally present in the cement mix will be converted to other compounds, often including silicates in addition to portlandite, as the concrete sets.

One aspect to consider with concrete is that the organic material in concrete binders if used, may provide a source of potential nutrients for microbial growth, promoting corrosion of the waste packages.

7.2.5.6 Apatite

One major drawback associated with apatite is that as a phosphate, it promotes the growth of iron-oxidizing microbes, which would hasten the waste package corrosion process. The corrosion products in turn would provide nutrients for continued microbial activity.

This material exhibits several of the characteristics that are desirable for a getter. It sorbs Np-237 perhaps adequately, has low solubility, and is chemically stable under expected repository conditions, and can be crushed to a fine size. It is not entirely clear whether the measured sorption arises from true surface adsorption or from precipitation of insoluble Np phosphate on the surface of the mineral grains. If the latter is the case, apatite may provide a longer retardation than would simple adsorption, because of the very low solubility of the Np phosphate. Apatite also has low adsorptive capacity for Tc-95m. The material tested (CRWMS M&O 1998c, Item 2, pp.15, 19) was obtained from North Carolina, but may not be available in sufficient quantities for use in Yucca Mountain. Other sources can probably be located. One potential source is from phosphate mines in Florida, but this will need careful evaluation because this material contains a substantial percentage of other minerals, such as calcite and possibly organic matter.

7.2.5.7 Basalt, Pyroxene, and Other Ferrous Silicate Materials

The consideration of basalt, pyroxene, or some other ferrous iron containing silicate, e.g., dunite, as a getter material arises from their potential to reduce pertechnetate, TcO_4^-, to tetravalent Tc, which is insoluble as TcO_2 and other solids. These silicate materials are very insoluble, which is desirable, but this also means that they will likely not react rapidly with TcO_4^- in solution. Moreover, they would need to be able to withstand exposure to atmospheric oxygen for a long time in order to remain in a reduced condition until breach of waste packages. It seems unlikely that they would react only very slowly as a reducing agent for O_2, but rapidly as one for TcO_4^-. Thus, their effectiveness as a getter may be low.

7.2.5.8 Iron and Iron Oxides or Hydroxides

The function of zero valent metallic iron would be essentially the same as for the ferrous silicates, as discussed in the preceding section. However, iron metal would become oxidized much more rapidly than the silicates, and, consequently, seems unlikely to survive chemically until the time needed to act as a getter. Nevertheless, it would oxidize to hematite and/or goethite, both of which are good adsorbers of actinides. Moreover, if the corrosion products of ferrous metals are still forming while the waste form is degrading, coprecipitation of actinides with the hematite or goethite is likely. This would constitute a reasonably stable immobilization of the radionuclides. Magnetite, Fe_3O_4, occurs both as a mineral that persists for very long geological times, as do hematite and goethite, and as an intermediate corrosion product on iron. All three of these iron minerals are abundant in iron ores. Their use as a getter should be as fine grained material to enhance their surface area and expose sorption sites to the water.

7.2.5.9 Borax

This mineral is very soluble in water. It would almost certainly be dissolved and flushed out of the drift before waste packages would breach.

7.2.6 Previous Sorption Experiments

Batch sorption experiments have been performed on crushed tuff and other minerals to determine the sorption coefficient for Np and other radionuclides. Synthetic goethite (an iron oxyhydroxide) possessed the greatest sorption capability for Np-237 with a K_d of $1.8x10^5$ ml/g.

Synthetic hematite (an iron oxide) also showed strong sorption capability with a K_d of $3.3x10^3$ ml/g (Triay et al, 1991, p.496, Table 2). However, other issues may exist regarding their thermodynamic stability over the long term.

Getter Material Properties (CRWMS M&O 1998d, Attachment I) contains a compilation of sorption data obtained from previous batch sorption and column experiments. CRWMS M&O 1998d, Attachment I, lists sorption coefficient (K_d) values for several radionuclides on various getter materials. CRWMS M&O 1998d, Attachment II presents the retardation factors calculated from the K_d values obtained for Np-237 and Tc-95m on apatite from the sorption report contained in CRWMS M&O 1998c, Item 2, pp. 15,19. The K_d values at a pH of 8 and at a temperature of 25°C were used in CRWMS M&O 1999a, Item 3.

7.2.7 Effects of Percolation on the Getter Barrier During Post-Closure

Current information is available for describing and evaluating the spatial variability of groundwater percolation fluxes for the six repository regions over the DRY, LTA, and SP climate (CRWMS M&O 1999a, Item 3, Attachment III, p.1 of 4). The effects of the variable groundwater percolation fluxes on the performance of the invert material under present DRY climate conditions, LTA and SP events will be determined.

7.2.7.1 Method of Analysis

The one dimensional advection/dispersion/diffusion/sorption equation presented in CRWMS M&O 1999a, Item 3, p.6 of 27 is used to evaluate the effects of advection, hydrodynamic dispersion, diffusion, and sorption on radionuclide migration rates through the getter. Only results from modeling of Case 1 are presented.

7.2.7.2 Description and Function of the Getter Barrier

The getter feature, like the diffusive barrier, can consist of a single material or multiple materials emplaced below the waste packages that delays the breakthrough of radioncuIdies through the process of diffusion. In addition to the mechanisms described previously, the getter barrier, being a chemically reactive material, can retard radionuclide migration through the mechanism of sorption. In this analysis there are two getter placement configurations. Both consist of gravel-sized crushed tuff and silt-sized apatite layers (4.3.1) but of varied thickness. The Case 1 getter configuration requires a 6.5 m diameter drift (4.3.2) with a 200 mm concrete liner (4.3.10). Case 1 getter configuration has gravel-sized crushed tuff and silt-sized apatite layers that are 0.5 and 1.2 m, respectively (4.3.2). Case 2 getter configuration has gravel-sized crushed tuff and silt-sized apatite layers that are 0.1 and 0.3 m, respectively (4.3.3). These materials are placed in continuous layers, extending along the length of drift used for emplacement. There are no piers used with this design. The distance from the base of the concrete invert to the top of the concrete invert is 0.855 m (4.3.11). The top layer of crushed tuff in the Case 1 getter configuration is above the top of the concrete invert, therefore the rail will have to be placed upon this top layer (4.3.5). The two configurations are illustrated in Figures 5 and 6.

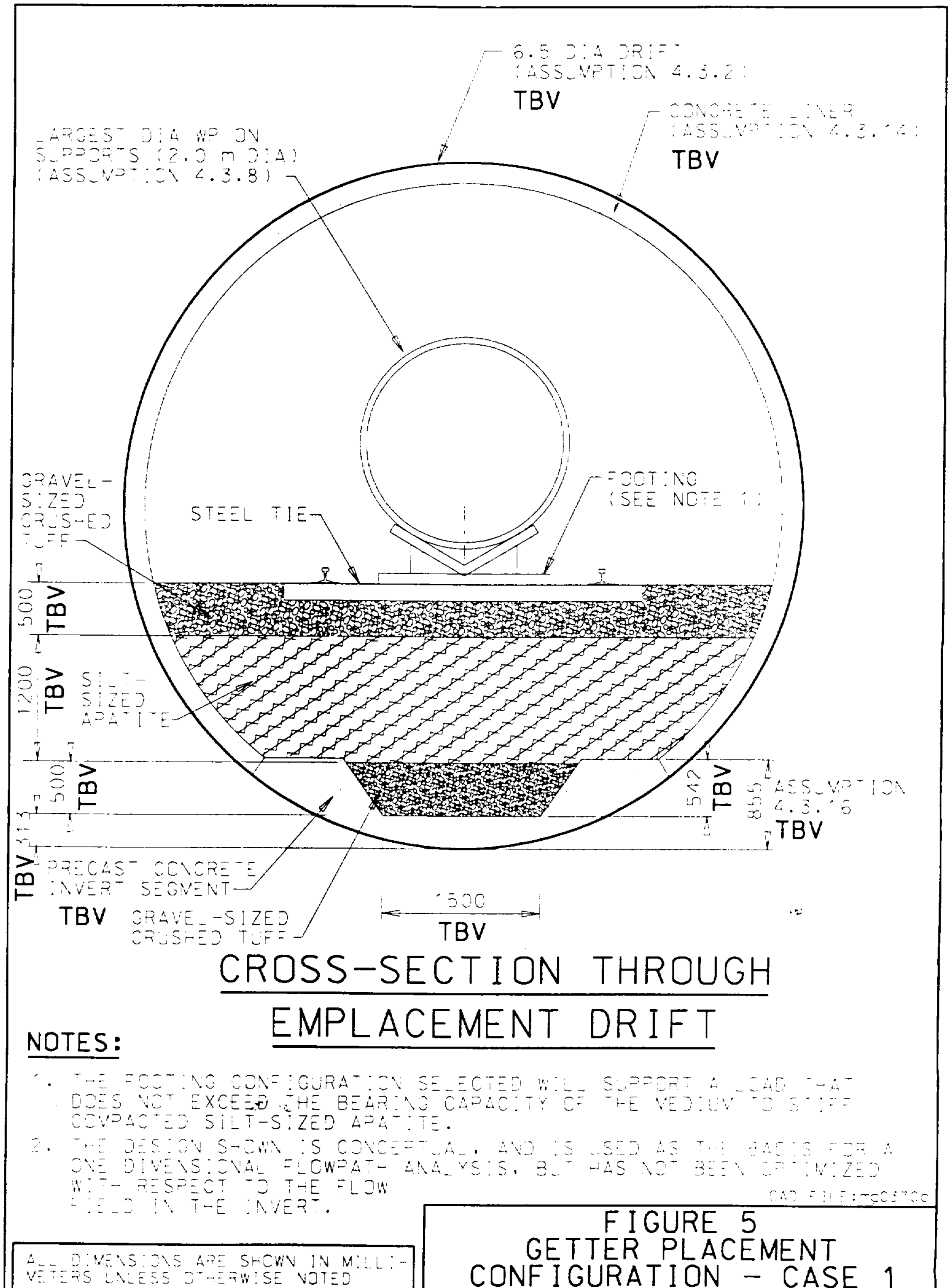

Figure 5. Case 1 Getter Configuration

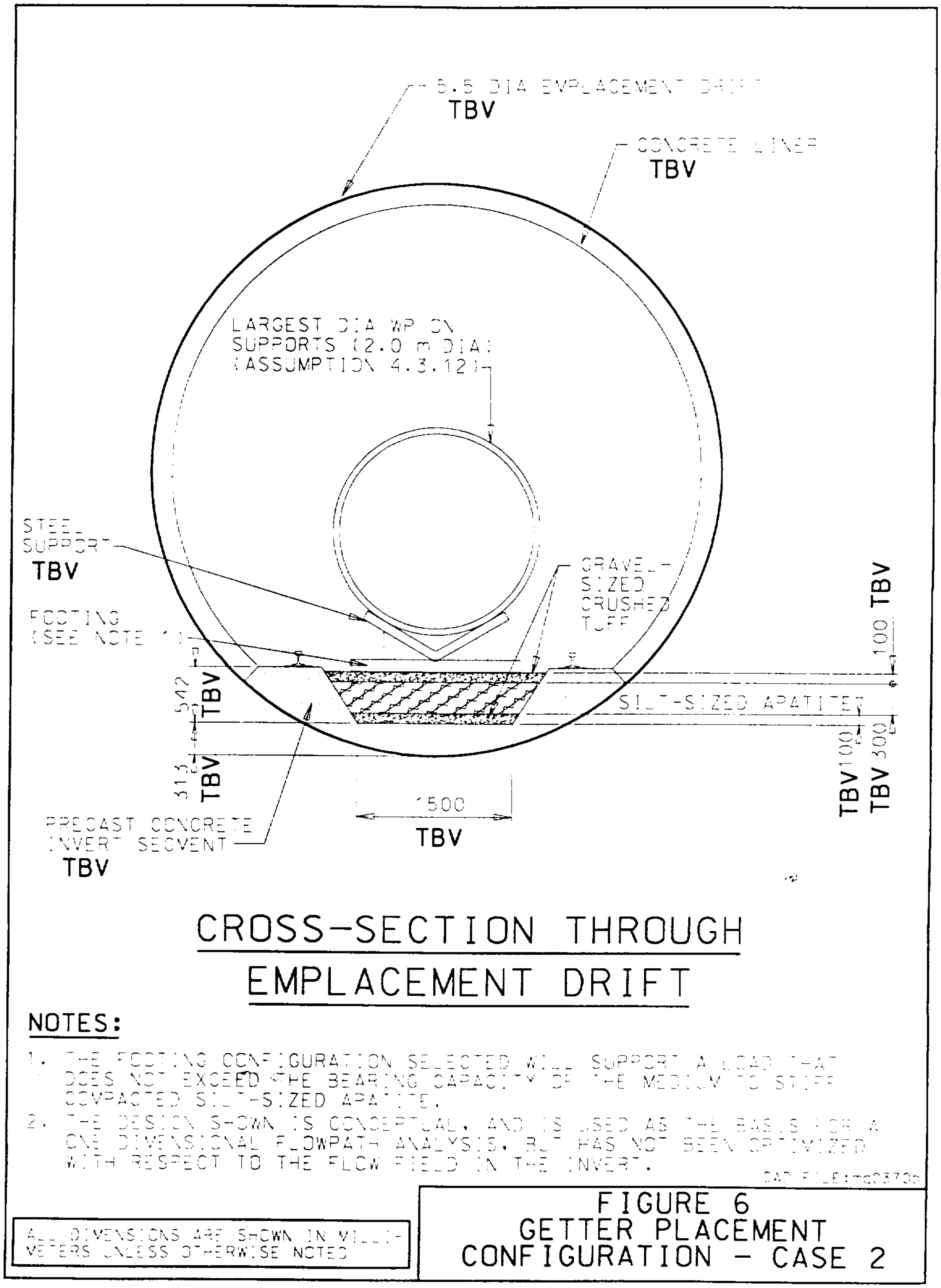

Figure 6. Case 2 Getter Configuration

7.2.7.3 Summary of Analysis of the Getter Barrier Performance

Porous mediums are evaluated, with regards to their ability to increase the breakthrough time from the EBS, via the mechanism of sorption. The concrete invert is assumed to be cracked at the time of waste package breach and not provide a barrier to radionuclide migration from the EBS (4.3.12). In the getter evaluation the convection-dispersion equation for nonadsorbing solutes is modified to account for the additional effect of sorption for sorbing solutes (CRWMS M&O 1999a, Item 3, p. 6 of 27). Through the mechanism of sorption, the longitudinal dispersion coefficient and the average linear velocity are effectively reduced by the retardation factor. The retardation factor is dependent on the dry bulk density of the getter material, the sorption coefficient of the radionuclides on the getter material and the moisture content.

$$R = \left(1 + \frac{\rho_b \cdot K_d}{\theta} \right)$$

where

R	=	Retardation factor,
θ	=	Volumetric moisture content
ρ_b	=	Dry bulk density(gm/cm^3), and
K_d	=	Sorption coefficient (cm^3/gm).

Apatite was selected as the getter material for this analysis for several reasons. First, apatite had the highest K_d value for Np-237 in comparison to the other minerals with the exception of synthetic goethite and synthetic hematite. Secondly, apatite is chemically and thermally stable, whereas the synthetic goethite and synthetic hematite are thermally instable. Thirdly, sorption data were available for the two major elements (Np and Tc). In addition, the LANL experiment (CRWMS M&O 1998c, Item 2, pp. 15 and 19) was performed not only at ambient temperature but also at higher temperatures and with pH-adjusted J13 groundwater.

As in the evaluation of the diffusive barrier, to apply the modified advection/dispersion/diffusion/sorption equation the waste package flow rates must be determined (CRWMS M&O 1999a, Item 3, Attachment III, pp.3 of 4. 4 of 4). The waste package flow rates are then used to calculate the volumetric moisture content and pore water velocities for the getter (silt-sized apatite) for the six repository regions, over three climate conditions. For the silt-sized apatite the volumetric moisture content and the pore water velocities are calculated in CRWMS M&O 1999a, Item 3, Attachment II, p. 7 of 10, 8 of 10, respectively. The mean volumetric moisture content for the DRY, LTA, and SP climates are presented in CRWMS M&O 1999a, Item 3, Attachment II, p.8 of 10).

Then, applying the Millington-Quirk tortuosity equation (CRWMS M&O 1999a, Item 3, p.5 of 27) the soil/liquid diffusion coefficient for the three climates can be determined by multiplying the binary diffusion coefficient via a ratio of the mean volumetric moisture content to the porosity. The hydrodynamic dispersion coefficient is determined by multiplying the pore water velocites by the dispersivity. Again, a dispersivity of 10 cm is selected based on engineering judgement, since, in the field, dispersivity ranges from 5-20 cm (Jury et al, 1991, p.222). The ratio of the hydrodynamic dispersion coefficients to the soil/liquid dispersion coefficients are then determined (CRWMS M&O 1999a, Item 3 , Attachment II, p.9 of 10). Ratios greater than one indicate that dispersion is dominant. A ratio less than one would indicate that diffusion dominates. For the DRY climate the ratio is less than one (e.g the hydrodynamic dispersion coefficient is less than the soil/liquid diffusion coefficient). Therefore, contaminant transport is dominated by diffusion. The diffusion/dispersion coefficient for apatite for the three climates is then calculated by dividing the effective dispersion/diffusion coefficient, which is the summation of the hydrodynamic dispersion coefficient and the soil/liquid diffusion coefficient, by the mean volumetric moisture content (CRWMS M&O 1999a, Item 3, Attachment I, p.10 of 10). The contaminant breakthrough curves for silt-sized apatite and other silt-sized getter materials are generated by applying the above parameters to the advective/dispersion/diffusion/sorption equation.

Table 2 lists the averaged K_d values for Np-237 and Tc-95m on the apatite at 25°C and 60°C for pH of 4, 6, 8 and 10 (4.1.2). The remaining experimental data for Np-237 and Tc-95m on apatite at 80°C can be found in CRWMS M&O 1998c, Item 2, p.15 and 19. In general, the K_d values for Np-237 in apatite tended to increase with temperature. The K_d values for Tc-95m showed very little or minimal sorption for apatite. The rise in temperature did not seem to influence sorption capability for Tc-95m. The K_d values for Tc-95m are used for Tc-99, since the chemical behavior of technetium doesn't depend on the isotopic weight but on the atomic number (4.3.8).

7.2.7.4 Results of Analysis of the Silt-Sized Apatite Getter Barrier

The analysis neglects reaction kinetic effects and the possibility of nonlinear sorption behavior caused by the exhaustion of sorption sites (CRWMS M&O 1997a, p.104). The linear sorption model represents a best case assumption for the possible benefit of a sorptive invert material.

The breakthrough curves for Np-237 and Tc-99, Figures 7 and 8 (4.1.3), are based upon retardation with advection/dispersion/ diffusion/sorption in the apatite. The results show that the average breakthrough time is increased by the retardation factor for the two radionuclides respectively. The results show that Np-237 experiences a significant retardation, while Tc-99 experiences a much lower retardation.

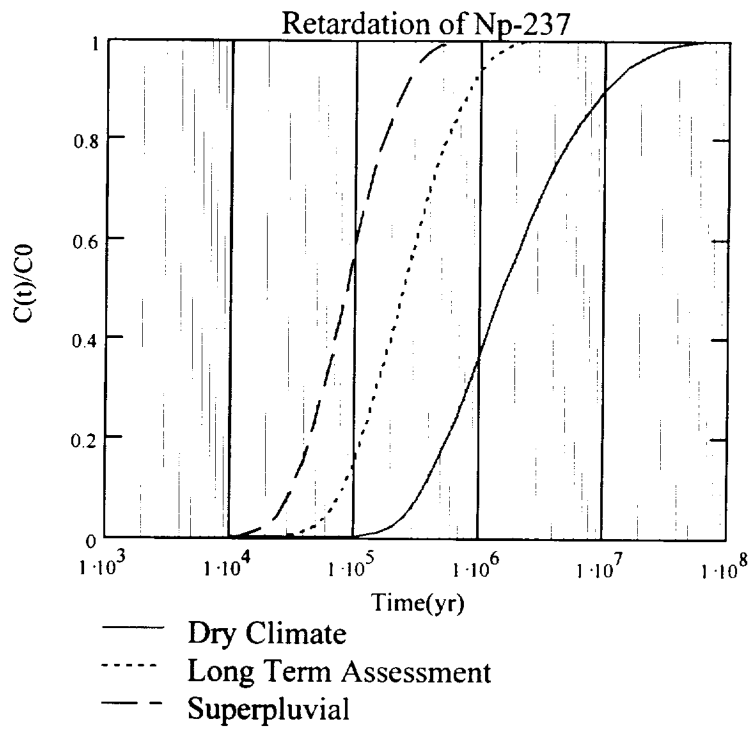

Figure 7. Breakthrough of Np-237 through Apatite Getter- (Case 1 Getter Configuration -1.2 m Thick Layer of Apatite)

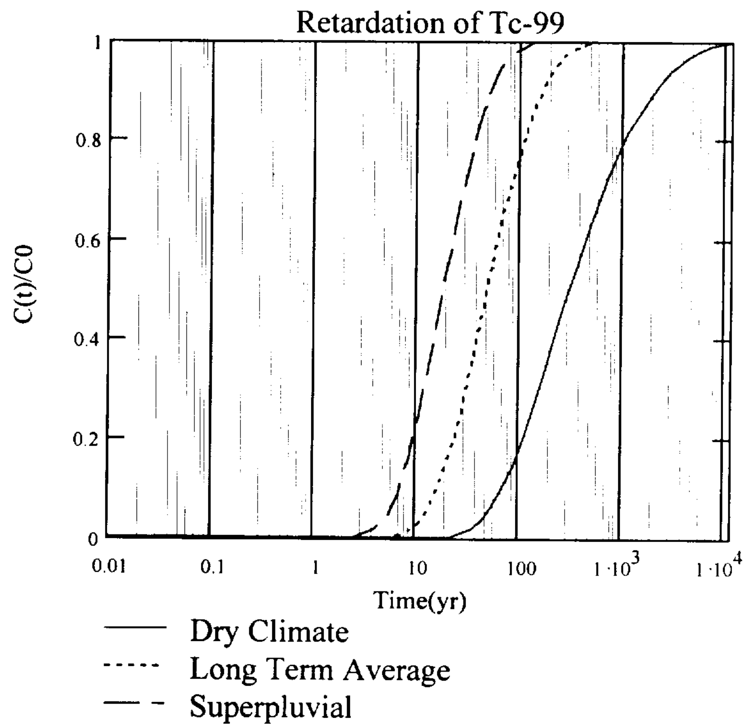

Figure 8. Breakthrough of Tc-99 through Apatite Getter (Case 1 Getter Configuration - 1.2 m Thick Layer of Apatite)

Figure 9 (4.1.3) presents the results for retardation of Np-237 in several materials, and compared with Figure 7 (4.1.3) the apatite provides a greater degree of retardation. Information on other oxides such as hematite, and goethite suggest substantially higher sorption when reacted with J13 groundwater. However, as mentioned previously other issues may exist regarding the thermodynamic stability of synthetic iron oxides over the long term. Further, information on the retardation of Tc-99 in these minerals is not available.

The getter barrier may be combined with other barriers with a resulting reduction in the average linear velocity through the invert. Under certain conditions in which the average linear velocity is small, molecular diffusion and chemical sorption become the dominant mechanisms and contaminant transport occurs more slowly. Figure 10 presents an analysis for diffusion/sorption for Tc-99 and Np-237 (4.1.3). The results of the analysis suggest that diffusion/sorption would increase the breakthrough time for these radionuclides.

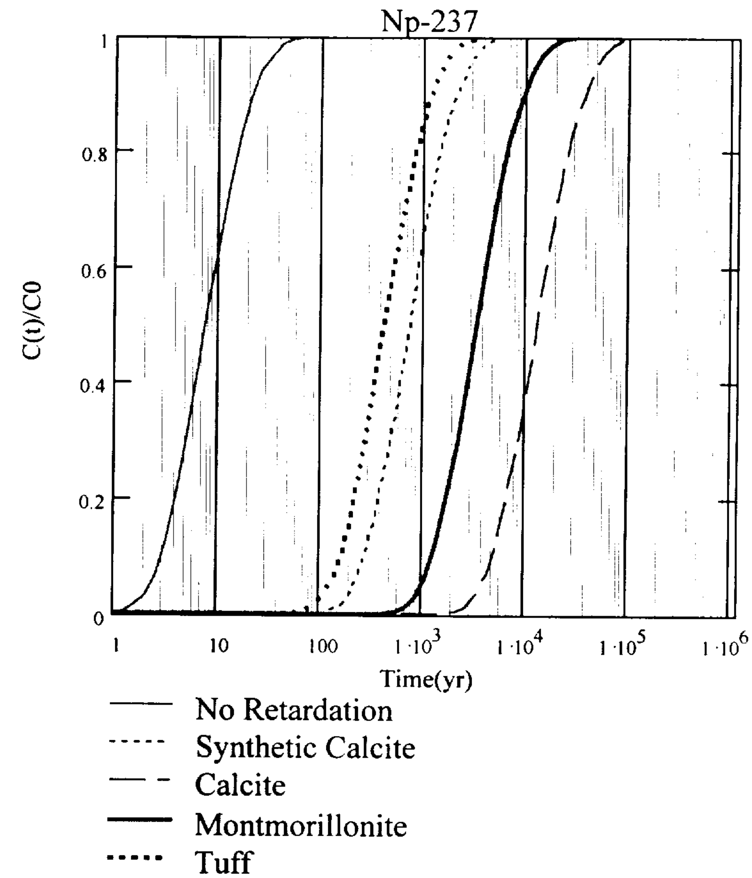

Figure 9. Breakthrough of Np-237 through Various Materials (1.2 m Thick Layer)

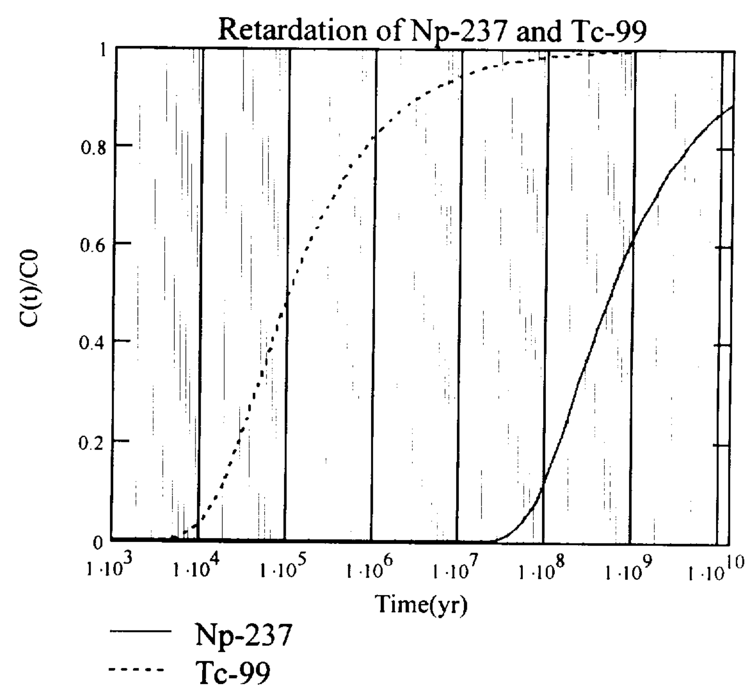

Figure 10. Breakthrough of Np-237 and Tc-99 for a Diffusive/Getter Barrier (1.2 m Thick Layer)

7.2.8 TSPA Results on the Performance of Two Getter Placement Configurations

The objective of this technical document is to evaluate what the performance of the repository would be if the getter feature was included in the LA Reference design, and to compare this performance to the predicted performance of the VA base case. The performance assessment calculations consider the effects of groundwater intrusion on the ability of the EBS to delay radionuclide migration to the accessible environment.

The performance of the repository is measured by its effectiveness in preventing or impeding the transport of radionuclides from the EBS to the accessible environment. Comparison of the predicted dose rates at the accessible environment for the getter cases with that of the VA base case will provide a basis for the inclusion of this feature, or this feature in combination with other features, in the LA design. The dose rate at the accessible environment is determined over two time frames. The first time frame is up to 10,000 years while the second is from 10,000 years up to 1,000,000 years.

The diffusive barrier case was not analyzed by Performance Assessment since the scoping calculations in Section 7.1.4 showed that radionuclide transport through the diffusive barrier is dominated by advection-dispersion flow and not by diffusion, resulting in early breakthrough from the EBS. Therefore, rendering the diffusive barrier ineffective as a barrier to the advective flow of radionuclides.

The Performance Assessment results (Figures 11, 12, 13, and 14) (4.1.4) use the expected values for all the distributed input parameters. The expected value runs from TSPA showed that for the first 50,000 years the dose rates are nearly identical for the base case and for either of the apatite layer thickness cases. The maximum allowable annual does rate (25 mrem/yr) (4.3.9) for an average individual living 20 km downgradient from the repository is never exceeded in the base case nor in the two getter configuration cases. In the first 50,000 years technetium is the primary contributor to the dose rate (CRWMS M&O 1998g, p.20 of 24). Given that the sorption coefficient for technetium on apatite is small, there is little improvement over the base case, which has zero sorption for technetium (CRWMS M&O 1998g, p.20 of 24).

After 50,000 years there is relatively insignificant improvement in performance for the 0.3 m apatite layer (CRWMS M&O 1998g, p.21 of 24), as shown in Figure 14 (4.1.4). However, the 1.2 m apatite layer does significantly reduce the dose rate between 50,000 and 300,000 years, primarily because of the increased sorption of neptunium on apatite (CRWMS M&O 1998g, p. 21 of 24), as indicated in Figure 12 (4.1.4). It is also possible to assess the delay achieved with the Case 1 getter configuration by comparing the time when a dose rate reaches the accessible environment for the case of the thick layer of apatite with that of the base case in Figure 12 (4.1.4). For example, a dose rate of 25 mrem/yr reaches the accessible environment 150,000 years after emplacement for the base case, and 225,000 years after repository closure for the Case 1 getter configuration (thick apatite layer). The delay benefits shown in Figure 12 (4.1.4) are consistent with the delays shown in the one dimensional advection/dispersion/diffusion/sorption equation presented for Np-237 in Section 7.2.7.4, Figure 7 (4.1.3). At a dose rate of 25 mrem/year the radionuclides reach the accessible environment at 150,000 years after repository closure for the VA base case and 225,000 years after repository closure for the Case 1 getter configuration (Figure 14) (4.1.4).

At the time of the first superpluvial climate , the peak dose for the Case 2 getter configuration is higher than the base case. Sorption of neptunium in the EBS is greater with the Case 2 getter configuration than in the VA base case. This results in a delay in breakthrough of neptunium from the EBS. Unfortunately, the delay in neptunium release happens in such a way that the release of neptunium is higher than the base case release of neptunium during the first superpluvial climate event, whereas for the base case, by this time, the release is decreasing during the superpluvial event. This higher amount of neptunium release during the superpluvial climate results in a higher annual radiological dose rate being observed for the Case 2 getter configuration compared to the base case. This may or may not be real. Likely, the peak radiological dose rates during the first superpluvial climate are not significantly different for the base case and the Case 2 getter configuration. Figures 12 and 14 (4.1.4) show that after 300,000 years, the dose rate with either getter configuration is essentially identical with the base case dose rate (CRWMS M&O 1998g, p. 21 of 24).

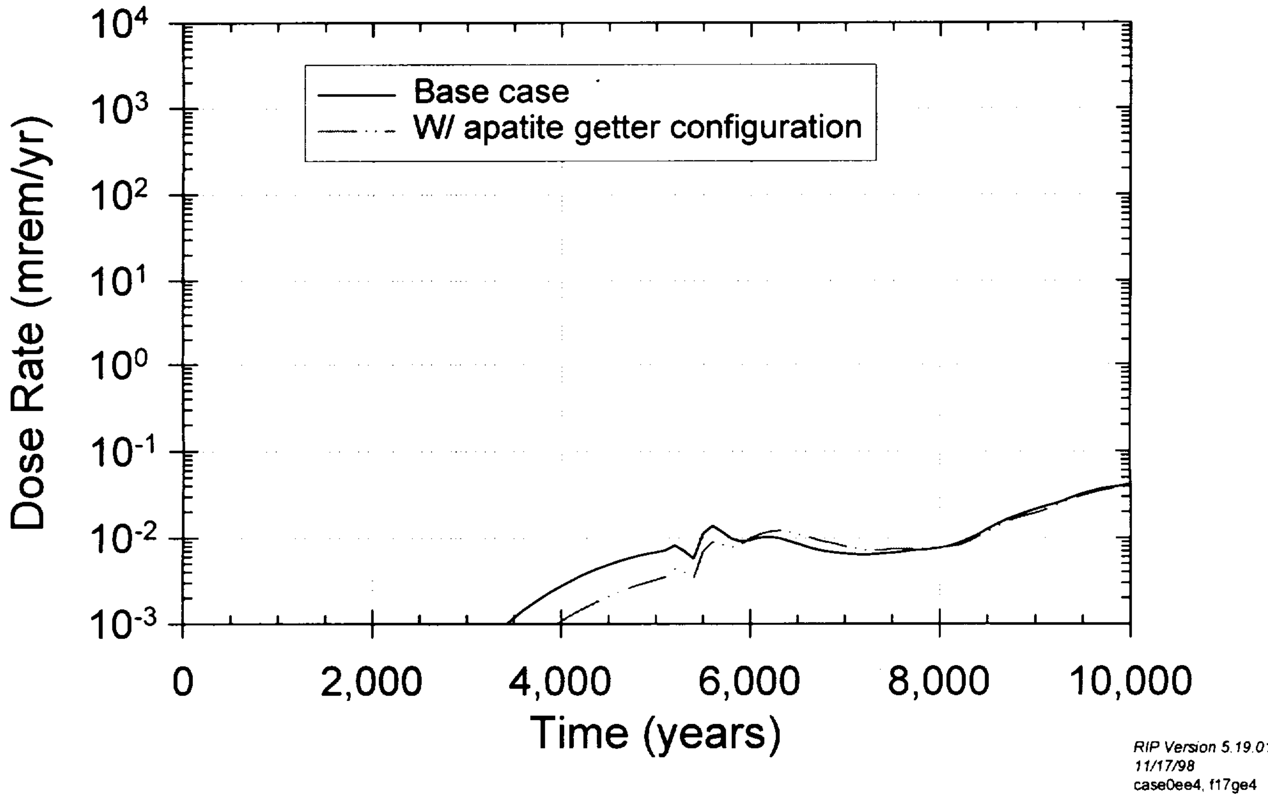

Figure 11. Case 1 Getter Configuration Dose Rate Results to 10,000 Years

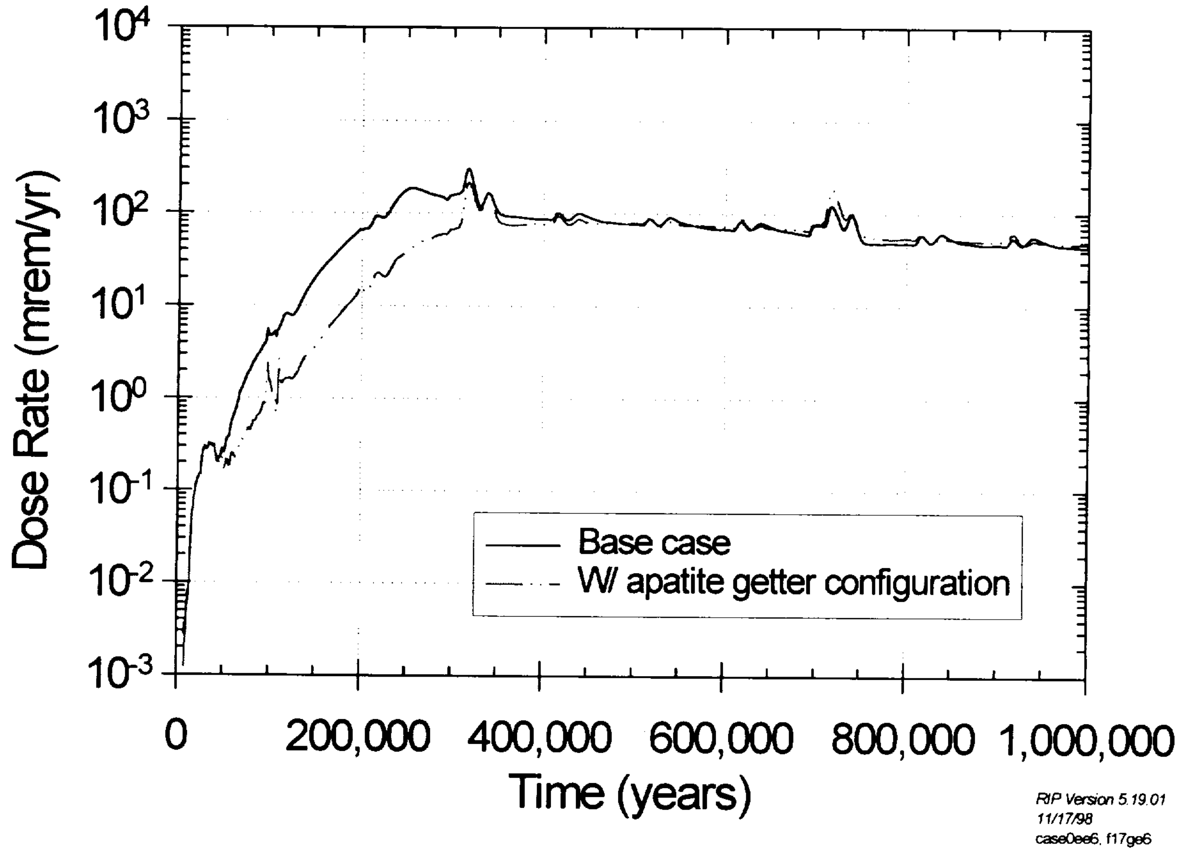

Figure 12. Case 1 Getter Configuration Dose Rate Results to 1,000,000 Years

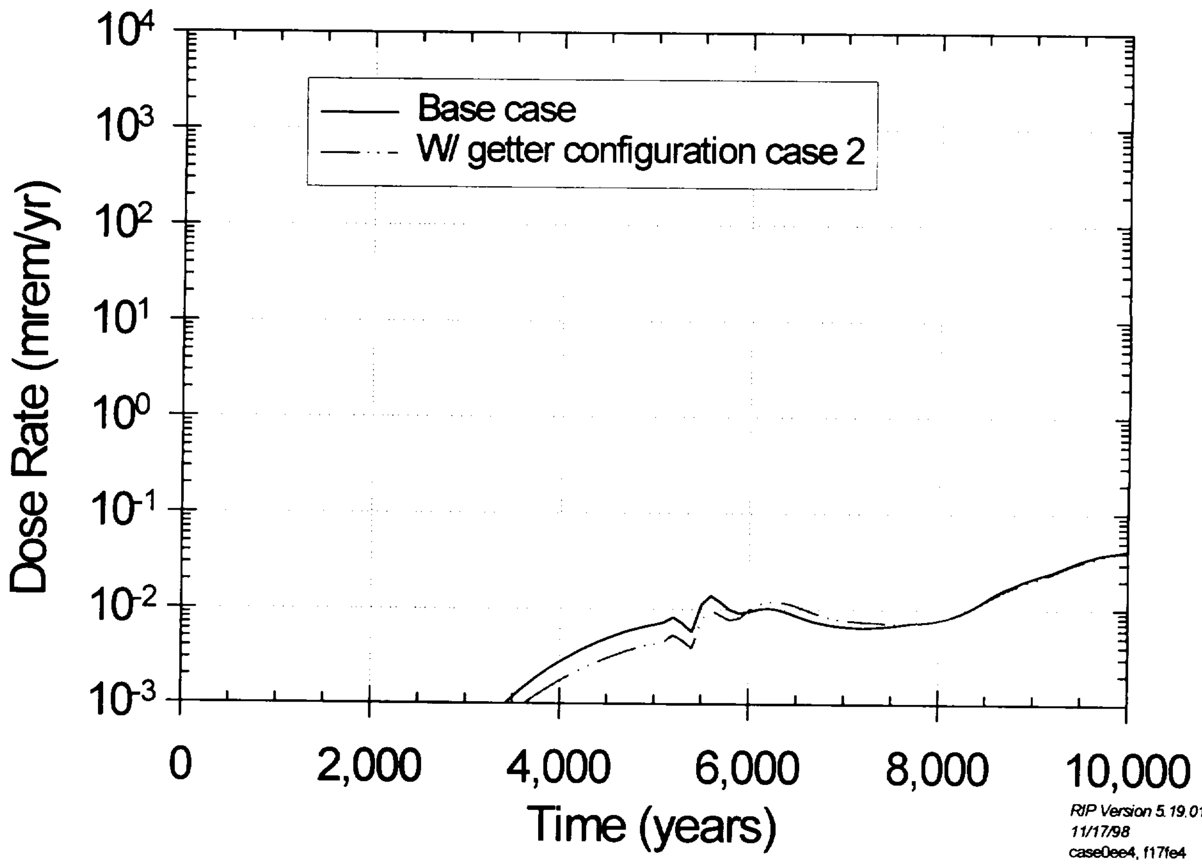

Figure 13. Case 2 Getter Configuration Dose Rate Results to 10,000 Years

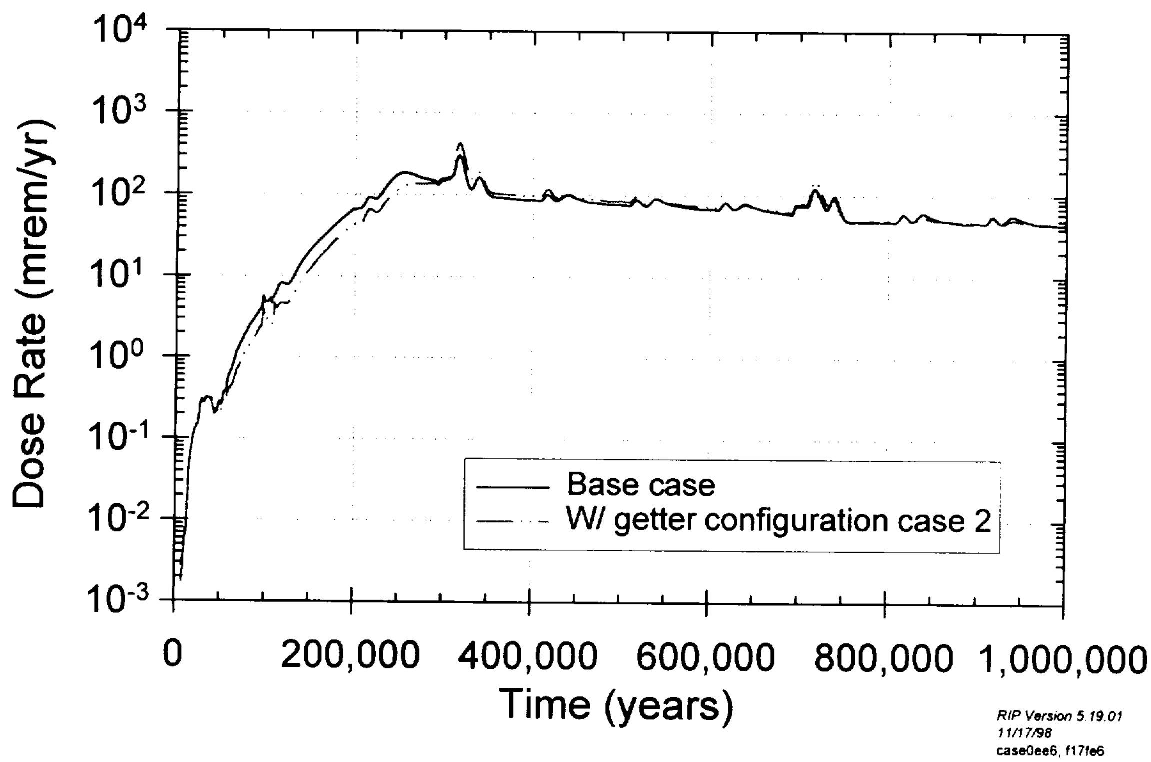

Figure 14. Case 2 Getter Configuration Dose Rate Results to 1,000,000 Years

7.2.9 Chemical Interactions that Affect Performance of the Getter Materials

There are interactions that could affect the performance of the getter. These undesirable interactions will be discussed further in the following sub-sections .

7.2.9.1 Dissolved Materials in the Groundwater

Dissolved materials in the groundwater could sorb onto the getter prior to the release of radionuclides from the waste package. This creates an uncertainty surrounding the availability of sorption sites when the waste packages finally breach.

7.2.9.2 Competition for Available Sorption Sites

Competition may exist for the available sorption sites between the radionuclides and the dissolved groundwater constituents after the waste packages breach.

7.2.9.3 In-drift Colloids Passing Through EBS without Sorption onto the Getter

Colloids are minute particles that travel with flowing water through the fractures and matrix of the rock without being sorbed. There are four types of colloids in the engineered barrier system: two natural types, iron-oxides and clays; and two types based on fuel degradation, spent nuclear fuel colloids and glass waste colloids. Certain colloids such as the clay and iron-oxides have the ability to bind radionuclides to their surfaces and travel out of the EBS without being sorbed onto the getter. Clay colloids enter the repository drifts in the water that passes through the unsaturated zone above the repository horizon. The iron-oxide colloids are produced within the drift as oxidation products of steel materials. Plutonium colloids, which are formed as a result of fuel degradation, can also travel outside of the EBS without being sorbed onto the apatite getter. There is no data on the adsorption of either technetium or neptunium colloids onto apatite. It is assumed that technetium and neptunium colloids do not sorb onto apatite (4.3.13).

7.2.9.4 Surface - Crusts/Intergranular Cement Forming Between the Grains of the Getter Material

The carbonation of concrete occurs when the CO_2 from the air penetrates the concrete and reacts with the hydroxides (predominantly calcium hydroxide) in the cement paste to form calcium carbonates ($CaCO_3$). However, calcium dissolved from the cement paste may not precipitate immediately as carbonate or may partially redissolve, and precipitate as a coating or cement the fine-grained getter material together. This would result in the getter material being by-passed by the water coming from the breached waste packages. The water would have a tendency to flow around the getter material instead of being wicked into it. An advantage with concrete carbonation is that it reduces the carbonate complexation of radionuclides in the concrete pore solutions, because of lowered pH, which in turn reduces the solubility of the radionuclides (CRWMS M&O 1997e, p.31).

Corrosion products from oxidation of waste package corrosion allowance materials (CAM), carbon steel waste package supports, and the rails are good adsorbers of actinides, lanthanides, and other metals. However, their adsorption sites may be rendered ineffective owing to occupation of the available sorption sites by actinides or lanthanides present in the groundwater prior to breach of the waste package. Such adsorption may or may not be reversible. Nevertheless, a sizable fraction of the corrosion resistant material and steels inside the waste package will still be uncorroded when a waste package is breached. The corrosion products of these metals would be available for sorption of radionuclides, as well as for incorporation of the radionuclides into the solid corrosion products through coprecipitation with hematite or goethite. A negative impact of this incorporation of radionuclides into the solid corrosion products would result if these products formed as colloids and the radionuclides were carried out of the EBS without being sorbed onto the getter.

As steels and iron-containing alloys corrode, at least a part of the iron oxidizes first to ferrous ion, Fe^{++}. Many ferrous compounds, e.g., ferrous bicarbonate, a common constituent of groundwaters, are modestly to highly water soluble. Moreover, the ferrous ion in solution oxidizes rather slowly, in a laboratory time frame, and, consequently, can be carried away from the metal by advection before it is oxidized further to insoluble ferric compounds, such as goethite and hematite. Therefore, the corrosion products that form in this way may potentially coat the getter or cement the fine grained getter materials together rendering the getter (e.g. apatite) ineffective as a sorbing barrier.

7.2.9.5 The Reversibility of the Sorption Process

Uncertainty exists regarding how long the radionuclides will remain sorbed onto the getter. Experiments (CRWMS M&O, 1998c, Item 2, pp. 17, and 19) do indicate that desorption occurs, but more slowly than adsorption. Thus, the getter can be expected to retard, but not permanently stop radionuclide transport.

7.2.9.6 Groundwater Chemistry Impacts on Getter Materials

Dissolution of the getter materials may occur before the waste packages breach, as a consequence of very low pH or chemical or biochemical interactions.

7.2.10 Rationale for Thickness of Apatite Layer

7.2.10.1 Calculation of Thickness of Apatite Layer

Tables 4 and 5 (4.1.6) indicate the minimum depth of getter required to absorb the entire inventory of Neptunium or Technetium for different drip rates at 25 °C and at 60 °C, respectively.

Table 4. Minimum Depth of Getter Required to Adsorb Entire Inventory of Np or Tc, 25 °C

Drip Rate (m^3/yr)	Time period, years	Element	Solution. Molality	Solid Conc.*	Grams of getter**	Volume, cm^3	Depth, cm
0.5	>600	Np	8.70E-06	1.74E-05	4.41E+06	2.94E+06	1.97E+01
0.15	600-17000	Np	1.10E-04	2.20E-04	3.48E+05	2.32E+05	1.56E+00
0.15	>17000	Np	8.50E-06	1.70E-05	4.51E+06	3.01E+06	2.02E+01
0.015	<3500	Np	1.00E-04	2.00E-04	3.83E+05	2.56E+05	1.72E+00
0.015	>3500	Np	8.00E-06	1.60E-05	4.79E+06	3.19E+06	2.15E+01
0.5		Tc	7.40E-04	3.70E-07	2.07E+08	1.11E+08	9.29E+02
0.15		Tc	1.00E-02	5.00E-06	1.53E+07	8.25E+06	6.87E+01
0.015		Tc	1.00E-02	5.00E-06	1.53E+07	8.25E+06	6.87E+01
* Moles of element/g apatite.							
** Grams of apatite required to adsorb the inventory of the element present in the waste package							
Inventory of Np-237 in waste package, moles	76.65						
Inventory of Tc-99 in waste package, moles	74.55						
Bulk dry density of silt-sized apatite , gm/cm^3 referred to as apatite fine sand (CRWMS M&O 1998d, p.5 of 9)	1.859						
Area of drift allocated per waste package, cm^2	1.20E+05						

Table 5. Minimum Depth of Getter Required to Adsorb Entire Inventory of Np or Tc, 60 °C

Drip Rate m^3/yr	Time period, years	Element	Solution. Molality	Solid Conc. *	Grams of Apatite **	Volume, cm^3	Depth, cm
0.5	>600	Np	8.70E-06	1.74E-05	4.41E+06	2.94E+06	1.97E+01
0.15	600-17000	Np	1.10E-04	2.20E-04	3.48E+05	2.32E+05	1.56E+00
0.15	>17000	Np	8.50E-06	1.70E-05	4.51E+06	3.01E+06	2.02E+01
0.015	<3500	Np	1.00E-04	2.00E-04	3.83E+05	2.56E+05	1.72E+00
0.015	>3500	Np	8.00E-06	1.60E-05	4.79E+06	3.19E+06	2.15E+01
0.5		Tc	7.40E-04	1.67E-06	4.60E+07	3.07E+07	2.06E+02
0.15		Tc	1.00E-02	2.25E-05	3.41E+06	2.27E+06	1.53E+01
0.015		Tc	1.00E-02	2.25E-05	3.41E+06	2.27E+06	1.53E+01

* Moles of element/g apatite.

** Grams of apatite required to adsorb the inventory of the element present in the waste package

Inventory of Np-237 in waste package, moles	76.65
Inventory of Tc-99 in waste package, moles	74.55
Bulk dry density of silt sized apatite gm/cm^3 referred as apatite fine sand (CRWMS M&O 1998d, p. 5 of 9)	1.859
Area of drift allocated per waste package, cm^2	1.20E+05

7.2.10.2 Discussion of Results

As Tables 4 and 5 (4.1.6) show, the concentrations of radionuclides at higher percolation rates are lower than for the lower percolation rates, owing to the greater dilution of the soluble corrosion or degradation products. This means that the concentration in the getter will be correspondingly lower, and that the thickness of getter required to adsorb the entire inventory will be greater.

The apatite getter thicknesses were calculated in an idealized manner. It is assumed that the effluent solution from the waste package percolates uniformly as a flat front through the getter, without taking into account dispersion, diffusion, or non-uniform trickling of the solution along preferential pathways (CRWMS M&O 1998d, p. 29 of 33). It similarly does not take into account the decreasing concentration of the solution as it encounters deeper and deeper layers of the getter. In other words the sorption is simulated in the present calculations as a sharp step function. Even in the absence of dispersion and diffusion the aqueous concentration of an adsorbing substance will decrease gradually as it percolates from layer to layer (i.e., some, but not all will be adsorbed in the first thin layer, then more in the next layer, etc.). Finally, if the adsorber is thick enough, the concentration will decrease into a non-linear region of the adsorption isotherm where the K_d approximation is no longer valid. Inclusion of dispersion and diffusion, and calculation of an ideal shape of a breakthrough curve, were not objectives of the calculations reported here, which were merely to provide a general indication of the required minimum thickness of getter (CRWMS M&O 1999d, p.29 of 33).

7.2.10.3 Calculation for Np

As shown in Table 4, a thickness of less than 1 m would, under the simplified and idealized conditions considered, suffice to adsorb all the Np-237, both at times soon after breach of the waste package when the pH is comparatively low and the solubility of the Np-237 is relatively high, and at later times at higher pH and lower Np-237 concentration (CRWMS M&O 1999d, p.29 of 33).

The Np-237 aqueous concentration varies in accordance with pH so long as solid NpO_2 is present. Eventually, at different times depending on the percolation rate and other factors, all the NpO_2 is expected to dissolve. The percolation rate over a range of about 8 mm/yr to about 100 mm/yr significantly affects the thickness of getter apatite required to adsorb all of the radionuclide. These percolation rates correspond to 0.015 m^3/yr to 0.5 m^3/yr (WP seepage flux rate or drip rate), respectively, of water entering a waste package. The range of required thicknesses of getter for Np-237 ranges from about 2 cm for conditions under which the pH is low and the Np-237 concentration relatively high to about 25 cm for conditions of minimal Np concentration (CRWMS M&O 1999d, p.29 of 33).

7.2.10.4 Calculation for Tc

As there is no pH or solubility control for Tc-99, it is all flushed from the waste package relatively early before the pH rises to a near neutral condition. For calculating the required thickness of apatite for Tc-99, an aqueous concentration in the mid-range of calculated values was chosen for each of the three percolation rates. At 60°C for the two lower percolation rates it appears that about 20 cm of apatite getter would suffice, ideally, to adsorb all the Tc-99, but at the highest percolation rate, over 2 m would be needed. If the thickness of emplaced getter is only about 1 m, the expectation would be that approximately half of the Tc-99 that first emerges from the waste package would be effectively adsorbed. Thereafter, the additional Tc-99 coming out of the waste package would pass through the getter without any retardation due to adsorption. After all the Tc-99 is removed from the waste package, the Tc-99 adsorbed on the getter would be gradually removed and flushed into the underlying rock. At 25 °C, much greater thicknesses of getter would be required, approximately 0.7 m at the lower infiltration rates and a little over 9 m at the fastest rate (CRWMS M7O 1999d, p.29 of 33).

Potential interference of adsorption of Np with adsorption of Tc, or vice-versa, was not evaluated. Nevertheless, no significant interference is expected because the Np will be in solution as positively charged ions, at least at pHs below 8 to 9, and the Tc will be in solution as negatively charged ions. In principle they should adsorb onto different kinds of sites on the getter, and therefore, not interfere with each other (CRWMS M&O 1999d, p.29 of 33).

7.3 THERMAL EFFECTS ON THE GETTER DURING POST-CLOSURE

The thermal effects on the diffusive barrier will not be discussed because of its poor post-closure performance, as a barrier on its own. The thermal effects on the getter during post-closure and the effect of the getter on the temperature of the waste packages are discussed below.

7.3.1 The Effects of the Getter on Temperature of the Waste Packages

The following paragraphs examine the effects of the two getter configuration cases on cladding temperature of the waste packages (CRWMS M&O 1999h, Attachment V) (4.1.5).

The getter configuration using a thin layer of apatite case is quite similar to the VA design, the only difference being that the apatite is placed in the invert trench which is empty in the VA design. The presence of the apatite and its accompanying crushed tuff does slightly change the view factor between the waste package and the bottom of the invert trench. However, the thermal conduction afforded by the mixture as compared with the air–filled volume should provide better heat transfer to the concrete invert and wall rock. The other components important in radiation heat transfer, such as, surface emissivity, view factor and surface area are slightly affected. The surface emissivity for the crushed tuff is assumed to be about 0.88 based on typical rock emissivities, which is the same as the value for concrete (CRWMS M&O 1999h, Attachment V, p.8 of 12). The view factor between the waste package and the crushed tuff surface is only 0.28 (CRWMS M&O 1999h, Attachment V, p.5 of 12). By inspection, it is readily seen that the change of the surface area for radiative heat transfer is small. Based on these considerations, it is judged that the effect on cladding peak temperature of the emplacement of the apatite is negligible.

The thin layer of apatite (Case 2 getter placement configuration) is assumed to be the bounding case for apatite temperatures. This is because the bottom surface of the WP is in closer proximity to the apatite than in the thick layer case. Only a 0.1 m thick layer of crushed tuff separates the waste package from the apatite in the thin layer case compared with 0.5m of crushed tuff in the thick layer case.

In case 1 the diameter of the drift has been increased to 6.5 m from 5.5 m. This should improve the radiative heat transfer and lower the cladding temperature, however, a large fraction of the free volume of the drift has been filled with apatite and accompanying crushed tuff. Since the surface area of the drift wall and the backfill are only slightly less than for the VA design, impact to the WP cladding temperature is judged to be negligible.

The emissivity of the crushed tuff is, as in Case 2, assumed to be 0.88, the same as concrete. The view factor from the waste package to the surface of the crushed tuff is 0.32 (CRWMS M&O 1999h, Attachment V, p.8 of 12), quite close to the value found in Case 2. Therefore, the capability for rejecting heat by radiative heat transfer should be similar to Case 2.

The thermal conductivity of the crushed tuff is in the range of 0.58 W/m K to 0.74 W/m K based upon laboratory experiments for crushed tuff with a porosity of 48 % (CRWMS M&O 1999h, Attachment V, p. 9 of 12). The thermal conductivity of the concrete is considerably greater, 1.4 W/m K. This implies that the crushed tuff surface will more quickly reach a higher temperature than the concrete due to less efficient heat transfer away from the drift. Further, the virgin tuff behind the liner has a thermal conductivity and heat capacity similar to concrete (thermal conductivity of between about 1.8 and 2.33 W/m K for the TSw2 unit and a heat capacity between about 864.9 and 948.03 J/kg K (CRWMS M&O 1999h, Attachment V, p.9 of 12). Thus there is some risk that the cladding temperature will be exceeded for the design-basis waste package. However, the porosity of the getter material will be selected to provide thermal properties that ensure the cladding temperature will not be exceeded. Therefore, the conclusion that cladding could be maintained below 350°C is acceptable for the depth of this evaluation.

7.3.2 The Effect of Heating from Waste Packages on Getter Behavior

The thermal effects on the diffusive barrier are not examined in detail because it is unlikely that the diffusive barrier would ever be implemented in the LA design given its poor performance in delaying breakthrough from the EBS, as previously described in Section 7.1.5. It is expected that the temperature effects on the diffusive barrier would be similar to the effects on the thin layer of apatite.

Since there was insufficient time to perform an analysis of the post-closure thermal effects on the behavior of the getter barrier, results from the TSPA base case thermal-hydrological calculations will be used. The TSPA-VA (DOE 1998b, Volume 3, p. 3-36, Figure 3-21) shows that the average waste package surface temperature is expected to drop below 100°C at around 1,000 years with the temperature of all waste packages dropping below 100°C well before 2,000 years. This would imply that the getter materials will also be below 100°C. To be conservative in measuring the performance of the getter, Performance Assessment has used the lowest K_d values for Tc-95m and Np-237 on apatite, which occurred at the lowest temperature tested (25°C) (CRWMS M&O 1998c, Item 2, p.15, 19). The sorption data show that the getter should perform better at higher temperatures (4.1.2).

7.4 SEISMIC EFFECTS ON THE DIFFUSIVE BARRIER AND GETTER DURING POST-CLOSURE

Seismic activity and subsidence are likely phenomena that will affect all aspects of the emplacement drifts during the Post-Closure period. The effect of vibration and material displacement will be evaluated.

7.4.1 Seismic Loading of the Diffusive Barrier and Getter

Large amplitude loadings are designated as those that cause or may cause a potential change in the strength of the soil. When considering the stability of cohesionless soils, it has been found that soil liquefaction is the most significant mechanism in altering soil structure, and in causing settlement. However, in a properly designed system the invert material would remain below saturation (volumetric moisture content less than the porosity of the material), and soil liquefaction would not be possible.

The invert material should be compacted to reduce the potential for vertical settlement in the event of repeated seismic events. The design of the invert should be combined with other features to prevent saturation of the invert to eliminate the potential for liquefaction. It is recommended that the invert materials be characterized in terms of the relative density properties, and that the materials be compacted with roller vibration in a multiple lift operation.

7.5 PLACEMENT METHODOLOGY FOR THE TWO GETTER CONFIGURATIONS

Among the issues to be discussed will be placement methodology for the two getter configurations, ventilation requirements, and the control of airborne particulates. In addition, the scheduling and cost impact of placing conditioned invert materials will be evaluated.

This technical document describes two placement configurations for the getter. Case 1 illustrates the optimum amount of getter that can be placed (4.3.2) while precluding the emplacement drift diameter and use of piers outlined in the VA design. Figure 5 illustrates a 6.5 m diameter drift (4.3.4) to accommodate the getter materials and the non-carry over gantry in the Case 1 design.

Case 2 (Figure 6) illustrates the maximum amount of getter material that can be placed within the 5.5 m diameter emplacement drift outlined in the VA Reference design (4.3.3). However, as in Case 1, piers are not used. Footings replace the VA pier design in Case 1 and Case 2. The design configurations with respect to thickness and type of materials, for both cases, are preliminary and are TBV.

The placement methodology for the diffusive barrier will not be discussed because it is unlikely that it would ever be implemented in the LA design given its poor performance in delaying breakthrough of radionuclides from the EBS, as previously described in Section 7.1.4.

However, given that its design is identical to the Case 2 getter placement configuration with the only difference being sand instead of apatite, we can assume that the placement methodology, scheduling, and costs for the diffusive barrier would be nearly the same as for Case 2 getter placement.

7.5.1 Placement Methodology for Case 1 and Case 2 Getter Configurations

Materials for Case 1 and Case 2

1,000 kg tote bags (bottom chute and drawstring arrangement to facilitate discharge)

72,000- 3m long carbon steel divider panels for material separation (apatite from gravel-sized crushed tuff).

Surface facilities

It is assumed that the apatite will be crushed off-site to a silt-size and delivered to the site in 1,000 kg tote bags. The tuff would be crushed on-site to gravel size. This would require a crushing plant and conveying system to a bin/silo with a chute to load the 1,000 kg tote bags.

Placement Procedure in Each Heading

1. Raw materials are transported on flat-bed rail cars to site.

2. Park on main at intersection of emplacement drift.

3. Disconnect locomotive from the train, hook it up to rail mounted crane (flat bed car with overhead crane).

4. Load materials from first transport car onto the flat bed car with overhead crane.

5. Rail mounted crane flat car is trammed to the (exhaust vent raise) to begin retreat.

6. Bagged getter and gravel-sized crushed tuff are individually picked up with the rail mounted crane, where the bags travel to the end of the crawler beam and then the materials are discharged into the appropriate section as described below.

7. A layer of gravel-sized crushed tuff is placed on the concrete invert floor. The getter material is placed on top of the layer of gravel-sized crushed tuff. A final layer of gravel-sized crushed tuff is placed on top of the getter and extended out to the invert walls (Case 2) or drift walls (Case 1).

8. Material will be graded, and compacted to the required density.

9. Continue until materials are consumed then tram back to main and switch empty car out to access next load of tote bags.

10. In the Case 1 configuration the steel ties and rails should be placed on top of the getter material as placement retreats towards the mains (4.3.5).

7.5.2 Dust Control Measures

The generation of dusts during the placement of the silt-sized apatite and gravel-sized crushed tuff is of concern. Ventilation will dilute the concentrations of dust in the air, however, the silt-sized apatite and fines may become airborne. Conventional methods of keeping dust levels down in underground headings, through application of a fine mist of water, may not be allowed. Therefore, the workers placing the materials will have to wear respiratory protection. In addition, the compaction equipment should be equipped with a cab maintained under positive pressure and supplied with filtered air. Air plate compactor hand tools should also be equipped with a dust collector if they are used during the tamping operation (CRWMS M&O 1998h).

8. CONCLUSIONS

This technical document was prepared in response to CRWMS M&O 1998j. The purpose of this document is to evaluate the diffusive barrier and getter under the waste packages design features relative to the VA Reference design. The evaluation assesses the potential of the diffusive barrier and getter features to enhance the post-closure performance of the Viability Assessment (VA) Reference Design.

This technical document is based on existing, unconfirmed input data that is considered to be TBV. It is not to be used as input to construction, fabrication, or procurement. Any use of information from this report is required to be tracked in accordance with NLP-3-15.

In summary, the analysis of the performance of the diffusive barrier, Section 7.1, indicates that at the expected seepage flux rates the diffusive barrier alone does not enhance the performance of the repository. However, if it were combined with one or more features that reduce the advective, then radionuclide transport through the diffusive materials would be dominated by diffusion, and their migration from the EBS impeded. Therefore, the time at which the radionuclides reach the accessible environment would be increased.

The analysis of the performance of the getter feature, Section 7.2.7.2, and TSPA post-closure assessment, Section 7.2.8, indicates moderate performance benefits for the repository can be achieved with the thick layer of apatite (Case 1 getter placement configuration). During the regulatory period (first 10,000 years after emplacement) the apatite does not retard radionuclide migration nor reduce the dose rate at the accessible environment. However, both a delay in the radionuclides reaching the accessible environment and a reduction in dose rates are observed for the period between 50,000 up to 300,000 years after repository closure for the Case 1 getter configuration. For example, the Performance Assessment results showed that at 200,000 years after repository closure the dose rates for the Case 1 configuration were a factor of five lower than the dose rates for the VA base case (Figure 12) (4.1.4). The results also showed that a significant delay in breakthrough through the apatite can be achieved with Case 1. At a dose rate of 25 mrem/year the radionuclides reach the accessible environment at 150,000 years after repository closure for the VA base case and 225,000 years after repository closure for the Case 1 getter configuration (Figure 14) (4.1.4).

This study only examined apatite as a getter and due to limited time was not able to examine other materials. Apatite is effective at adsorbing Np but is not effective at adsorbing Tc which is the radionuclide that is the largest contributor to the annual radiological dose rate in the first 10,000 years. Some limited information does exist on a few other potential getters (e.g. iron oxides). However, further work would be needed to evaluate the efficacy of these other getters.

The aspects of design features 16 and 17, which have the potential to enhance design performance in accordance with the LADS evaluation criteria (CRWMS M&O 1998j), were identified and evaluated relative to the VA Reference Design (Appendices A and B). A summary of the evaluation is as follows:

Post-closure Performance

The peak dose rate for the VA base case, Case 1, and Case 2 in the first time frame occur at 10,000 years, the values are basically the same and are estimated at 4.22×10^{-2}, 3.96×10^{-2}, and 4.15×10^{-2} mrem/year, respectively (Section 7.2.8). The peak dose rate for the VA base case, Case 1, and Case 2 in the second time frame occur at 317,000 years and are estimated at 300.9, 213.6, and 423.7 mrem/year, respectively (Section 7.2.8).

The Figure of Merit (FOM) values of the integrated dose over the two time frames, for the base case, Case 1, and Case 2 getter configurations are 25.02, 16.4, and 23.76 mrem/year, respectively (Section A.1).

A post-closure performance assessment was not conducted for the diffusive barrier because the diffusive barrier alone does not enhance the post-closure performance of the repository. It would have to be combined with one or more features that would reduce the advective-dispersion flow (Section 7.2.8).

Pre-closure Performance

The pre-closure performance assessments for the diffusive barrier and getter features were comparable to the VA reference design. Therefore a rating of 3 is assigned (Section A.2).

Assurance of Safety

The diffusive barrier provides an assurance of safety comparable to the VA design. The two getter cases have an assurance of safety that is approximately the same as the VA. Therefore, a rating of 3 is assigned (Section A.3).

Engineering Acceptance

The diffusive barrier without other barriers that would reduce advection has a moderately low potential for engineering acceptance and is assigned a rating of 2. The two getter configurations are comparable to the VA design. Therefore a rating of 3 is assigned (Section A.4).

Construction, Operations, and Maintenance

The designs of the diffusive barrier and getter features have moderate disadvantages in construction, operations, and maintenance and are therefore assigned a rating of 2 (Section A.5).

Schedule

The schedules for the construction of the two getter configurations are comparable to the VA design (Section A.6). A construction schedule for the diffusive barrier was not prepared because it is unlikely that the diffusive barrier would be included in the LA design given its poor performance (Section 7.1.4).

Cost

The total costs associated with the Case 1 and Case 2 getter configurations are estimated at approximately $1.4 and $1.2 billion, respectively. Therefore, a rating of 2 is assigned to both getter configurations (Table A-1).

Environmental considerations associated with the diffusive barrier and getter features are included in Appendix B. They were developed to provide technical information to the EIS contractor, but were not used in the LADS evaluation.

APPENDIX A

EVALUATION CRITERIA QUESTIONS FOR THE DIFFUSIVE BARRIER AND GETTER UNDER THE WASTE PACKAGE FEATURES

APPENDIX A

EVALUATION CRITERIA QUESTIONS FOR THE DIFFUSIVE BARRIER AND GETTER UNDER THE WASTE PACKAGE FEATURES

The questions pertaining to the evaluation criteria are presented in CRWMS M&O 1998j. For each evaluation criterion question, each feature is ranked against the VA base case. A rating of 1 to 5 is applied for each evaluation criterion question with the exception of post closure performance, cost, schedule and environmental considerations. A rating of one and two indicates significant to moderate disadvantages, respectively, associated with these design features, a three would indicate equivalence to the VA design, a 4 and 5 indicates moderate to significantly higher advantages, respectively, associated with these design features. The evaluation criteria are summarized in Table A-1.

A.1 POST-CLOSURE PERFORMANCE

This study only examined apatite as a getter and due to limited time was not able to examine other materials. Apatite is effective at adsorbing Np but is not effective at adsorbing Tc which is the radionuclide that is the largest contributor to the annual radiological dose rate in the first 10,000 years. Some limited information does exist on a few other potential getters (e.g. iron oxides). However, further work would be needed to evaluate the efficacy of these other getters.

Current analysis indicates that the peak dose rates, to an average individual of a critical group at a distance of 20 km from the repository site, for the first time frame (up to 10,000 years) for the VA base case, Case 1 and Case 2 getter placements are basically the same and are estimated at $4.22x10^{-2}$, $3.96x10^{-2}$, and $4.15x10^{-2}$ mrem/year, respectively (CRWMS M&O 1998g, p.20). The peak dose rates for the VA base case, Case 1 and Case 2 in the second time period occur at 317,000 years and are 300.9, 213.6, and 423.7 mrem/year, respectively(CRWMS M&O 1998g, p.20).

The PA results for Case 1 and 2 show that the releases to the accessible environment that occur at 4,000 and 3,600 years after emplacement, respectively are caused by a single juvenile failure at 1,000 years.

The Figures of Merit (FOM) for the VA base case and Case 1 getter configuration were calculated to be 25.02 mrem/year and 16.4 mrem/year, respectively (CRWMS M&O 1998g, p.20). A FOM value that is less than the VA base case FOM value indicates better performance in reducing the dose rate at the accessible environment over the period from 0 years to 1,000,000 years after repository closure. Therefore, the Case 1 getter configuration provides significantly better performance than the VA base case design.

The FOM for the Case 2 configuration was 23.76 mrem/year (CRWMS M&O 1998g, p20). This indicates insignificant performance benefit over the VA base case design.

No post-closure performance was performed for the diffusive barrier.

A.2 PRE-CLOSURE PERFORMANCE OF DIFFUSIVE BARRIER AND GETTER FEATURES

Nuclear safety applies to the Monitored Geologic Repository (MGR) during the pre-closure phase and is considered to address the radiological protection of workers and the general public. It is discussed in terms of safety analysis for design basis events (DOE 1998b, Volume 2, Section 2.2.)

The diffusive barrier and getter features do not have any potential effect on DBEs associated with surface facilities or operations. However, these features may have an effect on DBEs associated with subsurface facilities and operations since they are placed in the emplacement drifts. The following paragraphs are extracted from CRWMS M&O 1999f.

The diffusive barrier or getter configuration materials are placed before waste package emplacement. The potential mechanisms that could lead to a breach of a waste package include the following:

- Potential drops or impacts on a waste package during emplacement
- Rockfall onto a waste package

<u>Drops or impacts on waste package</u> - Distortion, dislocation, or debris-blockage of emplacement gantry rails may result in derailment or other malfunctions of the gantry system such that a waste package is dropped or impacted. Such events might be initiated by extreme settling and spill out of the compacted material onto the tracks which may cause misalignments of the pedestals and/or gantry rails that could affect emplacement/retrieval operations. This could result in derailment or blockage of gantry travel that may result in an impact or drop of a waste package. Case 1 getter configuration is judged to be more likely to experience such effects since the rail support is less rigid than in the diffusive barrier or Case 2 getter configuration.

The effects of vibratory ground motion during an earthquake is another possible mechanism for causing displacements of the diffusive barrier or getter material that could result in misalignment of waste packages and/or the rails. Seismic events (earthquakes) can also have a direct effect on emplacement operations, as well as cause damage to the waste package pedestals, or shake waste packages off of the pedestals. Such direct effects are potentially present without the diffusive barrier or getter materials being present.

Therefore, the presence of the diffusive barrier or getter is judged to have a small increase in the probability of a handling mishap during emplacement, relative to that of a rigid, concrete invert material that is not loaded with diffusive barrier materials or getter material.

So long as the resulting drop heights and impacts to a waste package are within the design basis of the waste package, there will no breach of a waste package and no release of radioactivity due to these events. In the Case 2 getter configuration and diffusive barrier configuration, it appears that the maximum potential drop height is essentially unchanged from the VA case. In the Case 1 getter configuration, however, should there be a concurrent drop or fall of a waste package and creation of a large chasm or void in the getter fill layer, the drop height could exceed the design basis of the VA waste package. Thus, Case 1 introduces a higher conditional probability of a radioactive release, given a drop scenario initiated by a gross separation of the compacted material.

Rockfall – If the diffusive barrier and getter configurations disturb or affect the stability of the ground support system, a rockfall onto a waste package may be more likely to occur. Since the upper surface of the getter material is open, no mechanism is identified for the material to exert extraordinary static forces on the invert cavity or on any other part of the ground support. Therefore, it is judged that the material by itself cannot affect the probability or consequences of a preclosure rockfall event.

However, the Case 1 getter configuration requires a larger diameter drift which permits larger mass keyblocks. Therefore, Case 1 increases the conditional probability that a waste package could be struck and breached, given the occurrence of a rockfall. The diffusive barrier and Case 2 getter configuration use the VA design for emplacement drift diameter; therefore, these features do not increase the probability of a rockfall. The effect of drift diameter on the annual probability of rockfall initiation has not been established.

With consideration of the placement location of the getter barrier, its material characteristics and placement design, it is judged that there is a small potential for increasing the probability of initiating a DBE with Case 2 and a larger probability for Case 1. In addition, Case 1 provides a greater potential for releasing radioactivity given the initiation of waste package drop events.

Should there be a mechanical breach of a waste package, the expected dose to the public at the pre-closure controlled area boundary will not exceed 5 rem from Category 2 design basis events (DOE 1998b, Volume 2, Section 3.4).

The pre-closure performance assessments for the diffusive barrier and getter features were comparable to the VA. Therefore, a rating of 3 is assigned for both the diffusive barrier and getter.

A.3 ASSURANCE OF SAFETY

The effects of potentially important uncertainties, such as those that stem from the introduced diffusive or getter materials, have not been analyzed with respect to whether the inclusion of these features in the repository design will provide greater safety assurance.

The potential effects of seismic activity have not been included in TSPA analyses however potential effects of seismic activity on the repository (DOE 1998b, Volume 3, Section 4.4.3)

- Vibratory ground motion and displacement from earthquakes could potentially cause a rockfall onto the waste packages.
- Changes in site hydrologic properties (such as change in flow patterns of groundwater near the waste packages or a change in elevation of the water table).
- Faulting near the repository could result in indirect effects such as the alteration of groundwater flow and transport paths.

These potential effects could possibly have an indirect impact on the assurance of safety provided by the getter, or any feature, including the VA, however, it would be unlikely.

Another disruptive event that could have an impact on the getter placement configurations, although unlikely, is nuclear criticality. If the getter material is very effective in sorbing the complete inventory of one or more fissile radionuclides released from the breached waste packages, a nuclear criticality situation might arise. Correspondingly, if the diffusive barrier is able to delay the breakthrough of radionuclides from the EBS, such that there is an accumulation of radionuclides within the diffusive porous medium, then a nuclear criticality situation may arise; however, it is unlikely. No specific calculations were done for apatite regarding the nuclear criticality issue. Therefore, this assessment would be considered conservative.

If the scheduled date regarding the acceptance of the LA design by the NRC is on target, then repository construction will begin in a few years. Given that emplacement of getter materials will occur at the time of emplacement drift construction, this leaves only a few years to reduce the uncertainties regarding this feature's impact on assurance of safety. However, it is possible to reduce the uncertainties by the time of construction through laboratory and quarter scale tests.

The diffusive barrier provides an assurance of safety that is comparable to the VA design. The two getter cases have an assurance of safety in post-closure that is approximately the same as with the VA. Therefore, a rating of 3 is assigned. There is some additional uncertainty as to how the getter will work, which will need to be resolved, but the getter does provide some potential additional defense in depth.

A.4 ENGINEERING ACCEPTANCE

The use of diffusive barrier or getter materials in the repository clearly falls under the Engineered Barrier System, a system that contributes to postclosure performance (DOE 1998b, Volume 2, Section 1.2.1.1).

Both the diffusive barrier and getter barrier support the third element of the repository safety strategy, controlling the mobilization rate of radionuclides (DOE 1998b, Volume 2, Section 8.2.2, Table 8-3)

Communication of the concepts and function of diffusive and getter barriers can be done in a clear manner. The resulting design of the diffusive or getter barriers, however, is fairly complicated and laborious in terms of the steps required for placement.

The analysis of how these features function and perform employs accepted engineering concepts of contaminant transport under vadose (unsaturated) zone conditions. The simple one-dimensional advection-dispersion-diffusion-sorption equation is used to demonstrate the post-closure performance of the diffusive barrier or getter in delaying radionuclide breakthrough from the EBS. Further analysis would be necessary to examine the effects of getter shape on the flow. However, with proper design it should not be difficult to assure adequate drainage that would significantly reduce the potential for ponding, and saturated conditions in the invert. In the *Analysis of a Single Backfill Material* contained in CRWMS M&O 1999a, Item 2, a calculation of the flow convergence or divergence for a cylindrical inclusion was presented. This calculation showed that the maximum increase in flux rate due to convergence would be about 2 times the farfield flux rate. For a maximum percolation rate of 300 mm per year, the flux rate due to convergence would be 600 mm per year. This value may be compared to the saturated hydraulic conductivity of a fine grained material or 7 X 10-5 cm/s or 18,000 mm per year. This value is a factor of 30 higher than the maximum percolation rate. It suggests, that under steady state conditions with adequate drainage, the getter is not likely to saturate.

Currently, there is no regulatory or engineering precedence for the implementation of a diffusive barrier or getter barrier in a MGR. More experimentation is necessary to determine the hydrological properties of the diffusive barrier and getter materials as well as the chemical properties of getter barriers. It is still possible, in the time remaining before the LA submittal date, to characterize various materials as to their suitability as barriers through laboratory and quarter scale experiments.

The diffusive or getter barrier design is constructable using simple equipment to deliver the materials and to compact the materials to the required density.

Potassium has been identifed as one of the components of an idealized microbial composition (DOE 1998b, Volume 3, Section 3.3.1.3, p.3-57). Therefore use of apatite as the getter material may enhance the corrosion rate of the waste packages because the apatite, being a phosphate, is an essential nutrient for the growth of microbes that may influence corrosion (DOE 1998b, Volume 3, Section 3.4.1.7). Therefore, utilizing apatite as the getter material, is contrary to limiting microbial activity (4.2.2). In an attempt to observe criterion 4.2.1 the apatite is surrounded with crushed tuff to prevent direct contact with the waste packages.

The diffusive barrier has a moderately low potential for engineering acceptance and is, therefore, assigned a rating of 2. The two getter configurations are comparable to the VA design with respect to engineering acceptance. Therefore, a rating of 3 is assigned.

A.5 CONSTRUCTION, OPERATIONS, AND MAINTENANCE

The following paragraphs discuss the impact of these features on radiation and industrial safety and were extracted from CRWMS M&O 1998h.

The diffusive barrier and getter would be placed at the time of construction. The diffusive barrier feature would have no impact on enhancing nor reducing worker radiation safety. The getter feature, however, may have an impact on reducing worker radiation safety since apatite often has a low level of uranium and thorium impurities. Industrial safety could be impacted because of the number and complexity of the tasks involved in the placement of the diffusive barrier or getter materials in comparison with the VA design.

Industrial hygiene concerns arise as a result of the inclusion of these features in the LA Reference design. The use of silt-sized apatite, and the gravel-sized tuff would result in dust generation during the getter placement operation, partially due to the loading and dumping operations and partially due to disturbance of the material stockpiles by the ventilation air flow. To reduce exposure to the respiratory fraction of silt-sized apatite and crushed tuff fines, the compaction equipment should be equipped with a cab kept under positive pressure and supplied with filtered air. Workers in the general vicinity should wear respirators.

During the tamping operation if air plate compactor hand tools are used they should be equipped with a dust collector. In addition, the handles of the hand tools should be padded to dampen the vibration.

Welding the steel divider plates, that are used to separate the apatite from the crushed tuff, will produce a number of contaminants (e.g. CO, O_3, NOx, metal oxides) depending on the type of welding performed (Shielded Metal Arc (SMA), Tungsten Inert Gas (TIG) or Metal Inert Gas (MIG)), the composition of base metal used, the coating on the stick (SMA), and the type of filler metal. Therefore, the welder and near-by workers could potentially be exposed to dusts, fumes, gases, and ultraviolet radiation. To adhere to OSHA industrial safety standards the welders will wear personal protective equipment (e.g. gloves, face shield, goggles, and respirators). The short duration of the welding jobs should not pose a significant health and safety problem.

The following paragraphs describe the potential impacts of the inclusion of the diffusive barrier and getter on equipment availability and on waste package emplacement throughput capability in comparison with the VA design.

A reliability, availability, maintainability (RAM) rating is typically applied to active devices (e.g. equipment). Availability is a joint measure of reliability and maintainability in that it is a measure of reliability in terms of mean-time-between-failures (MTBF) and maintainability in terms of mean-time-to-repair (MTTR). Equipment RAM is assessed to determine its impact on waste package emplacement throughput in the sense that failure and subsequent repair reduce the rate of throughput.

The inclusion of these features in the LA design could potentially impact throughput indirectly because more steps are involved and extra equipment required in the placement of the diffusive barrier and getter compared with the VA design. The additional steps may cause the construction to lag behind, and, if failure and repairs are excessive, construction may fall further behind with the result that the construction operations are not maintained sufficiently ahead of the emplacement operations. This would extend the overall construction schedule which would have a negative impact on emplacement throughput.

The following circumstances could lead to construction delays:

- Increased traffic in the mains causing construction delays because materials and supplies are being delivered not only for the TBM operations, but also for the diffusive barrier/getter operations.

- With the introduction of more equipment (e.g., more cars, locomotives and rail-mounted overhead crane-cars) to accommodate the placement process, one can expect more opportunities for equipment breakdown. The availability of the extra equipment will depend on the length of time the equipment can be operated without breakdowns and how long it takes to repair the equipment. The repair time would have to incorporate tear down time and travel time to a repair garage. If there are spare pieces of equipment on-site, availability may not be a major issue.

With these above described construction interruptions, the waste package emplacement schedule (throughput) could be affected.

The impact on inspection:

Additional inspection time may be necessary with the inclusion of these features in the LA design. No additional equipment would be necessary to perform the inspections than has already been indicated in the VA Reference Design.

The subsequent paragraphs discuss the impact that a diffusive barrier and getter would have on the ability to perform performance confirmation activities. The following paragraphs are based on CRWMS M&O 1999g:

The following changes to the Performance Confirmation activities will be necessary if the diffusive barrier or the getter under the waste package features are included in the LA design.

The diffusive barrier can not be effective at the flow rates predicted by Total System Performance Assessment for the six different repository regions, and three climates (dry, long-term average, and superpluvial). The diffusive barrier may be effective if the flow rate is decreased to an acceptable level. This would require the diffusive barrier to be combined with one or more features that limit flow rates onto the waste package.

For either the diffusive barrier or for the getter, additional laboratory material testing is required on the diffusive barrier or getter materials including flow and transport performance under a range of seepage flow rates.

Introduced materials specimen collection and laboratory testing is needed to assess the long-term performance of the apatite.

The presence of the diffusive barrier or the getter will not in itself physically impact the performance confirmation capabilities. The difference will be in the added testing, monitoring, data and specimen collection, and data analysis and reporting. The near term test plan will be expanded as well as long term testing. Performance modeling will be ongoing, data will be acquired for the added tests, and iterations will be made, as needed, to achieve confidence that engineered materials are performing as anticipated.

These additional features may impact performance requirements in other areas of the system and result in an increase the design margin in meeting post closure performance objectives. The impacts would reduce the magnitude of the performance confirmation program. The magnitude of the impact is not known at this time. As the assessments mature and design criteria are developed, it will be possible to complete this assessment.

The construction, operations, and maintenance issues identified for Performance Confirmation are comparable to those of the VA Reference Design. Therefore, the design for the Diffusive barrier or Getter is given a rating of 2 (CRWMS M&O 1999g).

A.6 SCHEDULE

Given the poor performance predicted for the diffusive barrier (Section 7.1.5) under the current seepage flux rates, this feature will not likely be included in the LA design.

If the getter feature is selected for use, it is likely that the Case 1 getter placement configuration will be chosen over the less costly Case 2 getter placement configuration because it provides significantly better performance than Case 2 (Section 7.2.8).

A detailed design of this feature could be developed before the License Application is submitted for review by the NRC in 2002.

The construction schedule of the Case 1 getter configuration has been defined to ensure the same daily advance rate as the 5.5m diameter TBM. Therefore, completion of the Case 1 getter placement would follow shortly after completion of TBM excavation.

A.7 COST

The Case 2 configuration is the least costly at $1.2 billion (4.1.7); however, it does not provide improved performance from the VA Reference design. The total cost associated with the Case 1 getter placement configuration was estimated at $1.4 billion (4.1.7).

Level of Confidence of Each Rating

The following paragraphs are extracted from *Design Input Request for LADS Phase I Confidence Assessments* (CRWMS M&O 1999c, pp. 12 of 26, 13 of 26).

Postclosure Performance (LDE) -

Diffusive barrier - Moderate (C) level of confidence. Performance will be tied to inflow of water so the level of uncertainty is high. The materials to be used are well characterized in the laboratory.

Getter - Moderately low (D) level of confidence. Geochemistry is highly uncertain.

Postclosure Performance (PA Analyst) -

Moderately low (D) level of confidence. There are many questions regarding the design and potential performance of this feature: how thick should the barrier be, will it become saturated or be washed away by the time radionuclides are released, will the material used improve the environment for microbes, etc.

Preclosure Performance -

High (A) level of confidence. No effect on DBEs.

Assurance of Safety -

Diffusive barrier - Moderate (C) level of confidence. (Same basis as in Postclosure performance)

Getter - Moderately low (D) level of confidence. (Same basis as in Postclosure performance)

Engineering Acceptance -

Moderate (C) level of confidence. Engineering protocols will be followed in design and construction plans.

Construction, Operations, and Maintenance -

High (A) level of confidence. Since this feature can be constructed before WP emplacement, there is high confidence in effective construction. No operations or maintenance will occur.

Schedule -

Moderately high (B) level of confidence. Emplacement of this feature would have to be meshed with other construction activities.

Cost -

Moderately high (B) level of confidence. Materials cost and construction are straightforward.

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
1. Post-Closure Performance 1) What is the peak dose rate to an average individual of a critical group at a distance of 20 km from the repository site and the time of the peak, considering two time periods a) Less than 10,000 years b) Between 10,000 years and 1,000,000 years	1) N/A	1a) 0.0396 mrem/year (CRWMS M&O 1998g, p. 20) 1b) 213.6 mrem/year at 317,000 years (CRWMS M&O 1998g, p.20)	1a) 0.0415 rem/year (CRWMS M&O, 1998g, p.20) 1b) 423.7 mrem/year at 317,000 years. (CRWMS M&O 1998g, p.20)	1) The getter Case 1, Figure 12, (4.1.4) provides both a delay of radionuclide breakthrough from the EBS and reduction in peak dose at the accessible environment between 50,000 and 300,000 years. The getter Case 2, Figure 13 (4.1.4), does not significantly delay migration of radionuclides out of the EBS nor reduce the peak dose in the first time frame. In fact, Figure 14 (4.1.4), shows that for the period between 10,000 -1,000,000 years, the peak dose (423.7 mrem/year) exceeds the base case peak dose (300.9 mrem/year) (CRWMS M&O 1998g, Item 1, p.20).
2) The Figure of Merit (FOM) of the integrated dose 3) Potential for Juvenile Failure exist	2) N/A 3) N/A	2) 16.4 mrem/year (CRWMS M&O 1998g, Item 1, p.20) 3) yes, at 1000 years (CRWMS M&O 1998 g)	2) 23.76 mrem/year (CRWMS M&O 1998g, Item 1, p.20) 3) yes, at 1000 years (CRWMS M&O 1998g)	

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
2. Pre-Closure Performance 1) Would the Diffusive Barrier and Getter features increase or decrease the probability of a Design Basis Event (DBE)?	1) 2	1) 2	1) 2	1) For the Diffusive Barrier (DB) and getter cases-extreme settling of diffusive material may cause misalignments of the footings relative to the gantry placement of waste packages leading to an impact or drop of the waste packages. Spill out onto the rail may cause derailment of the emplacement gantry. Earthquakes are another possible mechanism for causing displacements of DB or getter materials that could result in misalignment of waste packages and or rails (CRWMS M&O 1999f).
2)a) Would the Diffusive Barrier and Getter Features add a DBE? b)Is the new DBE bounded by other DBEs?	2)a)3 2)b)N/A	2)a)3 2)b) N/A	2)a)3 2)b) N/A	2)a) Not any more or less than the VA. (CRWMS M&O 1999f)
3) Would the Diffusive Barrier and Getter increase or decrease the consequences of a DBE?	3)3	3)3	3)3	3) Not any more or less than the VA. (CRWMS M&O 1999f)
4) Does the Diffusive Barrier and Getter increase or decrease challenges to the repository safety systems?	4)3	4)2	4)3	4) For the getter Case 1 it increases challenge to the repository safety system because the larger drift diameter might result in increased chance of rockfalls (CRWMS M&O 1999f).
5) What expected dose to the public at the pre-closure area boundary is calculated?	5) less than 5 rem per event	5) less than 5 rem per event	5) less than 5 rem per event	5) For the DB & Case 1 & 2 Getter configurations. If there was a breach as a result of a DBE, it would be within the regulatory limits for a Category 2 DBE (DOE 1998b, Volume 2, p. 3-7).
	Average = 3	**Average = 3**	**Average = 3**	

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

Evaluation Criteria Questions	Rating: Diffusive Barrier	Rating: Getter Case 1	Rating: Getter Case 2	Explanation for Rating
3. Assurance of Safety 1) Does your Diffusive Barrier and Getter have uncertainties in post-closure performance?	1)2	1)3	1)3	1) The Diffusive Barrier (DB) provide an assurance of safety that is comparable to the VA design. The two getter cases provide an assurance of safety in post-closure performance that is approximately the same as the VA. The getter cases may have the additional potential for nuclear criticality, however, it is unlikely.
2) What is the potential to reduce the uncertainties by the time of construction and closure?	2)3 **Average = 3**	1)2 **Average = 3**	1)2 **Average = 3**	2) It is possible to reduce the uncertainties by the time of construction through laboratory and quarter scale tests.
4. Engineering Acceptance 1) Can the function of each element in the design be clearly communicated?	1)3	1)3	1)3	1) The design of the DB and getter cases can be clearly communicated.
2) Which of the four elements of the repository safety strategy does it support: a) Limited water contacting waste packages b) long waste package lifetime c) low rate of release of radionuclides from breached waste packages d) radionuclide concentration reduction during transport from the waste packages.	2)c) 1	2)c)4	2)c)3	2) The diffusive barrier is supposed to support c) however the DB fails to provide a barrier to advective flow. The getter cases are supposed to support c). Case 1 provides both delay in breakthrough and a reduction of peak dose compared to the VA design. Case 2 doesn't significantly delay the release to the AE. Also it does not reduce the peak dose rate compared with the VA.

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
3) Does the engineering analysis follow accepted methods?	3)3	3)3	3)3	3) The methods of engineering analysis followed are equivalent to those of the VA.
4) Is there regulatory and/or engineering precedence for your design?	4)2	4)2	4)2	4) There isn't any specific regulatory or engineering precedence to follow.
5) What is the availability of qualified data to support your design likely to be in the LA time-frame?	5)1	5)3	5)3	5) More experimentation is necessary to determine required hydrological properties of DB and the getter materials as well as chemical properties of the getter. It is still possible to characterize these materials before the LA through laboratory tests and quarter scale tests.
6) Is the design constructable with proven methods?	6)3	6)3	6)3	6) The DB and getter case designs are constructable using simple equipment to deliver the materials and to compact the materials to the required density.
7) Are any high level design goals for the MGR violated by the use of this design	7)3	7)2	7)2	7) Use of apatite as a getter conflicts with the criterion 4.2.2 because the apatite promotes microbial growth which could lead to microbial induced corrosion (MIC) of the waste packages. In an attempt to observe criterion 4.2.1 the apatite is surrounded with crushed tuff to prevent direct contact with the waste packages.
8) If applicable, what is the effective lifetime of the feature or major component of the alternative in supporting the particular element of repository safety strategy.	8)1	8)3	8)3	8) If other groundwater constituents use up sorption sites on the getter material before breach of WP then the getter will be rendered ineffective in supporting the particular element of repository safety strategy.
	Average = 2	**Average = 3**	**Average = 3**	

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
5. Construction, Operations, and Maintenance 1) Would the diffusive barrier or getter features increase or decrease worker a) radiation safety and/or	1)a)3	1)a)3	1)a)3	1a) The diffusive barrier and getter cases would have no impact on enhancing nor reducing worker radiation safety (CRWMS M&O 1998h).
b) industrial safety?	1)b)2	1)b)2	1)b)2	1b) The DB and getter cases could affect industrial safety because of the number and complexity of tasks involved in their placement compared with current VA design. Industrial Hygiene concerns also arise: e.g. generation of respiratory fraction dusts from placement of silt-sized getter and gravel-sized crushed tuff, exposure to dusts, fumes, gases and ultraviolet rays produced during welding, exposure to vibration from hand held air plate compactor tools (CRWMS M&O 1998h).

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
2) Would the diffusive barrier or getter features increase or decrease reliability, availability, maintainability, and inspectability of manufactured and constructed items?	2)2	2)2	2)2	2) Equipment reliability, availability, and maintainability (RAM) is assessed to determine its impact on waste package emplacement throughput. With the inclusion of the DB and getter features there is potential for impact on throughput indirectly because construction might not be maintained sufficiently ahead of emplacement operations, if failure and repairs are excessive. Since more equipment is required to place the diffusive barrier or getter materials, it could result in more repairs. Additional inspection time may be necessary with the inclusion of these features however no additional equipment is necessary to perform the inspections than has been indicated in the VA design (CRWMS M&O 1998h).
3) Would the diffusive barrier or getter features increase or decrease throughput capability?	3)2	3)2	3)2	3) As discussed in 2) equipment downtime could extend the overall construction schedule, having a negative impact on emplacement throughput (CRWMS M&O 1998h).
4) Would the diffusive barrier or getter features improve or decrease the ability to perform performance confirmation activities?	4)3	4)3	4)3	4) The presence of the Diffusive Barrier or getter will not in themselves physically impact the Performance Confirmation capabilities. The difference will be in the added testing, monitoring, data and specimen collection, data analysis and reporting (CRWMS M&O 1999g).
	Average = 2	**Average = 2**	**Average = 2**	

Table A-1. Evaluation Criteria for the Diffusive Barrier and Getter Under the Waste Packages (Continued)

	Rating			
Evaluation Criteria Questions	**Diffusive Barrier**	**Getter Case 1**	**Getter Case 2**	**Explanation for Rating**
6. Schedule How does the diffusive barrier or getter features schedule compare to that for the VA reference design.	N/A	3	3	The Diffusive Barrier feature will not be included in the LA Reference Design because it does not enhance the performance of the repository. If the getter feature is selected for use it is likely that the Case 1 configuration will be chosen because it provides the best performance with regards to delaying breakthrough of radionuclides from the EBS and reducing the peak dose at the accessible environment. The construction of the getter Case 1 will run concurrently with the TBM excavation so that the completion of getter placement occurs just after TBM excavation is completed (Section 7.5.3 and 7.6.6).
7. Cost What is the difference in estimated. total cost relative to the VA reference Design?	N/A	2	2	The total costs associated with the Case 1 and Case 2 getter configurations have been estimated at $1.4 and $1.2 billion (4.1.7).
8. Environmental Considerations -associated with these features.				Refer to checklists in Appendix B for environmental considerations related to the materials and placement operations associated with the diffusive barrier and getter design features.

APPENDIX B

ENVIRONMENTAL CONSIDERATIONS ASSOCIATED WITH THE DIFFUSIVE BARRIER AND GETTER FEATURES

APPENDIX B

ENVIRONMENTAL CONSIDERATIONS ASSOCIATED WITH THE DIFFUSIVE BARRIER AND GETTER FEATURES

Described below is an evaluation of the environmental issues to consider with respect to the materials and operations associated with placement of a diffusive barrier or getter. A checklist format was utilized in the evaluations. Environmental considerations are not subject to QARD requirements (DOE 1998a).

B.1 ENVIRONMENTAL CONSIDERATIONS ASSOCIATED WITH THE DIFFUSIVE BARRIER FEATURE

- Impacts to land use and ownership

  Land use - Approximately 1 million cubic meters of material will be needed for this feature. Up to 100% of this amount could be depleted uranium, if it turns out to be the selected backfill material. About 2.5 acres of surface area is needed for a stockpile of two months supply (about 55,000 m^3 of material), and this may represent new land not included in the reference design.

  Land ownership – No impacts.

- Impacts to air quality

  Nonradiological impacts – If the material contains some fines, there may be some dust problems associated with the barrier material. The equipment used on the surface to move the material will give off some emissions. Underground, electric equipment will be used that have no emissions.

  Radiological impacts – If the chosen material is depleted uranium, there will be an increase in the amount of radon. The radon gas may be underground as well as on the surface. The radon may escape through ventilation raises into the atmosphere and disperse.

- Impacts to hydrology, including surface water and groundwater

  If depleted uranium is used, there may be an increase in the contamination of water because there will be more radioactive material placed underground and may be without the benefit of containerization or other engineering barriers.

- Impacts to biological resources and soils

  The size of the stockpile will be 2.5 acres by 7.62 meters high. There will be no changes to impact the life patterns of wildlife. The change in noise and ground vibration will only be caused in the construction phase of the barrier. The subsurface and surface temperatures are not expected to change. The only requirements for outdoor lighting are for the roads that will be used for safe transportation of the material.

- Impacts to cultural resources

  There will be a need for approximately 2.5 acres for storage, and this land will be required before emplacement of the waste packages.

- Socioeconomic impacts

  There will be no significant increase in the number of workers.

- Impacts to occupational and public health and safety

  There will be a slight increase in industrial accidents because of the additional operations needed to implement this feature. If depleted uranium is chosen as the diffusive barrier material, there will be an increase of radiological dose to the workers.

- Noise impacts

  Occupational noise will occur from the transportation and implementation of the diffusive barrier.

- Impacts on aesthetics

  There will be a storage unit for the material. This will cover about 2.5 acres. Night lighting may be needed for the safe transportation of the material.

- Impacts to utilities, energy, materials, and site services

  There will be no apparent increase in the amount of power and fossil fuels needed for the implementation of these features. This is considering that waste emplacement is happening at the same time. Approximately 310,000 cubic meters of material will be required.

- Impacts to management of repository generated waste and the use of hazardous materials

  If depleted uranium is used for this feature, some additional management will be required, such as to control and record dosimeter readings and worker exposure to the radioactive material.

- Impacts to environmental justice

  No impacts.

- Summary of primary impacts on 3 thermal loads (high, medium, low)

  No studies have been done to evaluate this impact of this feature on the thermal loadings.

- Summary of primary impacts on packaging options for transportation:

  No impacts.

- Summary of primary short term impacts (including operations, retrieval, and closure)

  The diffusive barrier material will be implemented during operations prior to the emplacement of the waste packages, and it may extend the period required for the work force. This has no impact on retrieval or closure.

- Summary of primary long term impacts (after closure)

  The long-term impact is slowing the fluid movement to the natural environment, thereby improving waste isolation.

B.2 ENVIRONMENTAL CONSIDERATIONS ASSOCIATED WITH THE GETTER FEATURE

- Impacts to land use and ownership

  Land use - About 2.5 acres of surface area is needed for a stockpile of two months supply (about 55,000 m^3 of material), and this may represent new land not included in the reference design.

  Land ownership – No impact.

- Impacts to air quality

  Nonradiological impacts –If the material contains fines, there may be some dust problems associated with the barrier material. The equipment used on the surface to move the material will also give off some emissions. Underground, electric equipment will be used, in turn, having no emissions.

  Radiological impacts – No impact.

- Impacts to hydrology, including surface water and groundwater

  No impacts.

- Impacts to biological resources and soils

  The size of the stockpile will be 2.5 acres by 7.62 meters high. There will be no changes to impact the life patterns of wildlife. The change in noise and ground vibration will only be caused in the construction phase. The subsurface and surface temperatures are expected not to change. The only requirements for outdoor lighting are for the roads that will be used for safe transportation of the material.

- Impacts to cultural resources

  There will be a need for approximately 2.5 acres, and this land will be required before emplacement of the waste packages.

- Socioeconomic impacts

  There will be no significant increase in the number of workers.

- Impacts to occupational and public health and safety

  There will be a slight increase in industrial accidents because of the operations needed to implement this feature. There will be no changes in radiological doses.

- Noise impacts

  There will be an occupational noise from the transportation and implementation of the getter material.

- Impacts on aesthetics

  There will be a storage unit, 2.5 acres, for the material that will impact the terrain and view. Night lighting will be needed to light the roads for the safe transportation of the material.

- Impacts to utilities, energy, materials, and site services

  There will be no apparent increase in the amount of power and fossil fuels for the implementation of these features. Approximately 310,000 cubic meters of material will be required.

- Impacts to management of repository generated waste and the use of hazardous materials

  No impacts.

- Impacts to environmental justice

  No impacts.

- Summary of primary impacts on 3 thermal loads (high, medium, low)

  No studies have been done to evaluate the impact of this feature on the thermal loadings.

- Summary of primary impacts on packaging options for transportation:

  No impacts.

- Summary of primary short term impacts (including operations, retrieval, and closure)

  The getter material will be implemented during operations prior to the emplacement of the waste packages, and it may extend the time period required for the work force. This feature has no impact on retrieval or closure.

- Summary of primary long term impacts (after closure)

  The long-term impact is for improved waste isolation through the retardation of radionuclide transportation.

APPENDIX C

RATIONALE FOR DETERMINING THE NUMBER AND SIZE OF FOOTINGS

APPENDIX C

RATIONALE FOR DETERMINING THE NUMBER AND SIZE OF FOOTINGS

Since this technical document is a scoping exercise the getter configuration design is preliminary and conceptual. Further analysis is necessary to examine the differential settlements of the supports due to the effects of seismicity and rockfalls. The more advanced analysis could result in getter configuration designs that differ from the ones presented in this document.

This calculation only attempts to show that it is feasible to place a waste package on a getter of silt-sized material. If the getter has an nominal allowable bearing pressure of 3 ksf (4.3.6) then the waste package can be supported with four 4ft x 4ft footings.

The actual getter concept shows the getter embedded in gravel-sized crushed tuff, and this configuration will support a significantly higher load. The gravel sized crushed tuff could be compacted to a density that would provide the same bearing capacity of the silt-sized apatite. Confinement of the silty getter and the depth of burial will give a higher bearing capacity.

Calculate the number and size of supports required.

1) Force (F) = mass x gravitational constant
F= 83,000 kg (4.3.7) x 9.81 m/s^2
F= 814.2 kN

For example if 4 supports used:
4 supports = 203.6 kN/support
Converting from kN to kips (1 kip = 1000 lbs = 4.5 kN) divide by 4.5

Therefore, **45 kips/support**

The size of the footing is selected on the basis that its bearing capacity does not exceed the allowable bearing capacity (3ksf) of the material (getter and crushed tuff) below the footing.

Trial and Error approach:

If 4 supports were used:

A footing 2ft x 4ft would give a bearing pressure of = 45 kips/8 ft^2
= 5.6 ksf
A footing 3ft x 4ft would give a bearing pressure of = 45 kips/ 12 ft^2
= 3.75 ksf
A footing 4ft x 4ft would give a bearing pressure of= 45 kips/ 16 ft^2
= 2.81 ksf

The 4ft x 4ft (1.22m x 1.22m) provides more than adequate support.